

EARTHQUAKES IN THE EASTERN UNITED STATES

HEARINGS
BEFORE THE
SUBCOMMITTEE ON
INVESTIGATIONS AND OVERSIGHT
AND THE
SUBCOMMITTEE ON
SCIENCE, RESEARCH AND TECHNOLOGY
OF THE
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CONTENTS

WITNESSES

May 23, 1984:	Page
Dr. Otto W. Nuttli, professor of geophysics, Department of Earth and Atmospheric Sciences, St. Louis University, St. Louis, MO; Dr. Arch C. Johnston, director, Tennessee Earthquake Information Center, Memphis State University, Memphis, TN; and Dr. Joanne M. Nigg, acting director, office of hazard studies, Arizona State University, Tempe, AZ..	6
Dr. Samuel W. Speck, Associate Director, State and Local Programs and Support, Federal Emergency Management Agency, Washington, DC; Dr. Carl W. Hall, Acting Assistant Director for Engineering, National Science Foundation, Washington, DC; and Dr. John W. Lyons, Director, National Engineering Laboratory, National Bureau of Standards, Washington, DC; accompanied by Dr. Richard N. Wright, Director, Center for Building Technology, National Bureau of Standards.....	66
Dr. Robert M. Hamilton, Chief Geologist, U.S. Geological Survey, Reston, VA, accompanied by Dr. John R. Filson, Chief, Office of Earthquakes, Volcanoes and Engineering, U.S. Geological Survey; and Robert B. Minogue, Director, Office of Nuclear Regulatory Research, Nuclear Regulatory Commission, Washington, DC.....	134
September 12, 1984:	
Dr. William J. Hall, professor of civil engineering, head, Department of Engineering, University of Illinois, Urbana, IL.....	213
John R. Longenecker, Deputy Assistant, Uranium Enrichment and Assessment, Department of Energy, Washington, DC, accompanied by Dr. James E. Beavers, Martin Marietta Corp.....	233
Dr. Thomas D. O'Rourke, associate professor, School of Civil and Environmental Engineering, Cornell University, Ithaca, NY; Dr. Anshel J. Schiff, professor, Department of Mechanical Engineering, Purdue University, Stanford, CN; and Dr. Irving J. Oppenheim, associate professor, Department of Architecture and Civil Engineering, Carnegie-Mellon University, Pittsburgh, PA.....	264

APPENDIXES

Appendix I: Study of earthquake recurrence rates.....	311
Appendix II: Hearing charter.....	366
Appendix III: An assessment of damage and casualties for six cities from a great earthquake.....	371

EARTHQUAKES IN THE EASTERN UNITED STATES

WEDNESDAY, MAY 23, 1984

HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND
TECHNOLOGY, SUBCOMMITTEE ON INVESTIGATIONS AND
OVERSIGHT, AND THE SUBCOMMITTEE ON SCIENCE, RE-
SEARCH AND TECHNOLOGY,

Washington, DC.

The subcommittees met, pursuant to call, at 9:45 a.m., in room 2325, Rayburn House Office Building, Hon. Albert Gore, Jr. (chairman of the Subcommittee on Investigations and Oversight) presiding.

Mr. GORE. The subcommittees will come to order.

I would like to welcome all of our guests and witnesses. Joining with the Science, Research and Technology Subcommittee—joining with that subcommittee, the Subcommittee on Investigations will now begin this hearing.

On the average, a damaging earthquake occurs in the Eastern United States every 25 years, and a large one occurs about every 50 to 100 years. For example, the largest earthquake ever in the 48 contiguous United States occurred near New Madrid, MO, in 1811 with a magnitude of an incredible 8.7 on the Richter scale. It rang church bells in Boston. Another large earthquake occurred in Charleston, SC, in 1886. Other large earthquakes have occurred in the Boston-New York area.

Since these earlier earthquakes, many smaller shocks have been recorded. In 1984, for example, over 50 earthquakes have been associated with the New Madrid Fault—that is, tremors. Most of these shocks are too small to be even felt, let alone cause damage, but they serve evidence of the continuing activity at the New Madrid Fault located near the Arkansas-Missouri-Tennessee border.

This scientific data leads to the inescapable conclusion that earthquakes pose a potential hazard in the Eastern United States. A repetition of the New Madrid earthquake at the present time would cause extremely serious damage. Current projections indicate that such an earthquake should probably not happen for hundreds of years, even though smaller, but still damaging shocks could occur within the next decade.

A significant step in addressing earthquake preparation was taken on April 17, 1984, when the Federal Emergency Management Agency announced the funding of a Central U.S. Earthquake Consortium. The member States are Arkansas, Illinois, Indiana, Ken-

tucky, Mississippi, Missouri, and Tennessee. The \$300,000 grant will be used to develop a 5-year earthquake preparedness plan.

The importance of developing preparedness plans can be demonstrated by looking at a FEMA study underway to assess the damage and casualties for six cities resulting from a great earthquake in the New Madrid seismic zone. A new quake of 8.5 on the Richter scale would cause severe damage to surrounding cities. According to the report, there would be loss of electrical utilities, water systems would be unavailable, natural gas systems would be damaged and shut down. Transportation links would be similarly affected. The report also projects that medical and other emergency services would be disrupted.

The full FEMA report, when released, will depict general estimates of casualties, damage and disruptions resulting from the projected earthquake. Other scientists have calculated that currently the stress built up in the New Madrid Fault, if released, would result in an earthquake of approximately 7.6 on the Richter scale. We are interested in hearing from today's witnesses when and where this type of stress could be released as an earthquake. In looking at all of these facts, it seems to me that there is no cause for alarm, but there are lots of reasons for preparation.

In today's hearing, we will examine the accuracy and adequacy of these scientific studies. Presently, there are more questions than answers regarding earthquakes in the Eastern United States. For example, when will the next large earthquake occur? Where will it be located? Are the Federal Government's activities, both in earthquake prediction and preparation, adequate?

The witnesses today should give us information that will be valuable in evaluating the Earthquake Hazard Reduction Program.

At this point, I want to ask unanimous consent to include in the record the statement of the ranking minority member of this subcommittee, Joe Skeen, who is on his way and will be given an opportunity to make his comments in person. But I want to reserve this point in the record for them.

[The opening statement of Mr. Skeen follows:]

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, D.C. 20515

May 23, 1984

Opening Statement

for the

Honorable Joe Skeen, Ranking Republican Member
Subcommittee on Investigations and Oversight

Thank you very much, Mr. Chairman.

This morning's hearing on hazards associated with earthquakes in the Eastern United States is an important one. In many instances, scientific research on eastern earthquakes is providing data to help solve problems of national significance.

A recent report of the National Research Council concluded that the establishment and operation of regional seismographic networks to monitor earthquake activities are providing important information not only to programs such as the mitigation of earthquake hazards, but also to the safe siting of dams, power plants, and other critical facilities throughout the country. I am looking forward to learning more about these networks from our witnesses, and how they are coordinated among agencies having jurisdiction over earthquake programs.

Let me just conclude by saying that while I have never considered myself to be an "easterner" either by geographic location or disposition, I am told

that eastern earthquakes, for geoscientific purposes, are considered to be those areas of seismic activity east of the Rocky Mountains -- which includes my own state of New Mexico. In fact, I learned this morning that a minor earthquake registering 2.7 on the Richter scale was recorded on Monday in Tucumcari, New Mexico, just west of the Texas/New Mexico border. I know that even this minor earthquake is significant, however, because of the important data it will bring about the seismic characteristics of the affected region.

Again, I am looking forward to today's hearing, especially because of the distinguished list of witnesses who have honored us with their presence here today. I want to join with the Chairman in thanking them for assisting this Subcommittee and bringing this important issue before the Congress.

Mr. GORE. Now I want to recognize my colleague from California, Congressman George Brown, Jr., who is undoubtedly the most knowledgeable person on Capitol Hill when the subject of earthquakes is under discussion. We are glad to have you with us here today, Congressman Brown.

Mr. BROWN. Thank you very much, Mr. Chairman.

I want to commend you for scheduling these hearings. I think they are timely and important, and the attendance here this morning and the wide range of witnesses, I think, is an indication of the significance of that.

In this room, which is dominated by evidence of our great scientific triumphs in space, we may tend to forget that over the last generation we have made similar great scientific strides in other fields, including the Earth sciences. And particularly out of the research and geophysics, the development of the theory of plate tectonics and other related additions to our knowledge, there came to be an understanding in much more specific terms of the nature of earthquakes and their impacts, and even to some degree what could be done in terms of predicting and possibly even mitigating the damage.

It was based upon this evidence of a really massive increase in our scientific knowledge that led Senator Cranston and myself in the 1970's to introduce legislation which eventually became the Earthquake Hazard Reduction Act of 1977. And in that act, Congress expressed their own feelings that the losses and destruction caused by earthquakes could be substantially reduced through the development and implementation of Earthquake Hazard Reduction Programs--measures.

This act directed the President to establish and maintain a National Earthquake Hazard Reduction Program, not just a California Hazard Reduction Program. One of the political problems we face in the Congress is the feeling of many Members that our interests were purely parochial, but this was not a problem that extended to other parts of the United States, and, of course, this

hearing will contribute to the alleviation of that sense of parochialism that I and other Californians have felt. All or part of 39 States lie in regions having major or moderate seismic risk. And the National Hazard Reduction Program was established to ensure a coordinated national response to a national problem.

As the chairman has indicated and others have indicated, the probability of a major earthquake occurring in the East is quite low, compared with California. However, moderate to severe earthquakes have occurred and will occur again. More than in most other parts of the United States, the earthquake hazard problem is compounded by high population density, many old and large buildings, and a high degree of modern industrialization, including, of course, the phenomenon of very vulnerable installations such as nuclear powerplants with a high hazard in the event that they are seriously disrupted.

I look forward to hearing in more detail today about what has been learned from current research, about gaps in research knowledge that exist. I feel very strongly addressing the Eastern earthquake problem can only help to strengthen the overall national effort, and strengthening the overall national effort to earthquakes, in turn, strengthens our national capability to respond to crises of all kinds. It is this focus that I am particularly interested in making also.

Thank you very much.

Mr. GORE. Thank you.

I would like to ask unanimous consent that we reserve a space in the record for any comments from Chairman Doug Walgren of our sister subcommittee and from Representative Judd Gregg, ranking minority member of the Subcommittee on Science, Research and Technology.

[The opening statement of Mr. Walgren follows:]

OPENING REMARKS OF DOUG WALGREN

I commend my colleague, Mr. Gore for initiating this hearing on earthquake hazards in the States east of the Rocky Mountains. The public may not realize that some of the strongest and most extensively felt earthquakes in the Nation's history have occurred in the East.

Although damaging earthquakes are about ten times more common in Southern California than they are in the East, they have occurred and will occur in the future. The East faces potential losses because of the large population, the large number of buildings that are not earthquake resistant and the number of critical facilities located throughout the area. A repeat of the the New Madrid, Missouri earthquakes of 1811-1812, would have serious social and economic impacts on the Nation.

Progress has been made on understanding of past earthquakes in the East, however, we still do not fully understand much of the past and continuing seismic activity. In this hearing we must assess the status of earthquake research in this area. Also, we must raise the issue of devising an effective seismic safety policy.

Now is the time to address potential earthquake hazards before the next damaging earthquake occurs.

Mr. GORE. Now, without any further ado, I want to ask our first panel to come to the witness table: Dr. Otto Nuttli, professor of geophysics with the Department of Earth and Atmospheric Sciences at St. Louis University; Dr. Arch Johnston, director of the Tennessee Earthquake Information Center at Memphis State Uni-

versity; Dr. Joanne Nigg, acting director of the Office of Hazard Studies at Arizona State University in Tempe, AZ.

We are delighted to have all three of you here and, without objection, the full text of your prepared statements will go into the record at this point. If you want to summarize any of your prepared statements, you may feel free to do so.

We will begin with Dr. Otto Nuttli from St. Louis University, professor of geophysics. We are delighted to have you here, Dr. Nuttli. You have testified before the Science and Technology Committee in the past, and we have benefited from your insights, and we are very pleased to have you lead off this hearing this morning. Welcome.

STATEMENTS OF DR. OTTO W. NUTTLI, PROFESSOR OF GEOPHYSICS, DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES, ST. LOUIS UNIVERSITY, ST. LOUIS, MO; DR. ARCH C. JOHNSTON, DIRECTOR, TENNESSEE EARTHQUAKE INFORMATION CENTER, MEMPHIS STATE UNIVERSITY, MEMPHIS, TN; AND DR. JOANNE M. NIGG, ACTING DIRECTOR, OFFICE OF HAZARD STUDIES, ARIZONA STATE UNIVERSITY, TEMPE, AZ

Dr. NUTTLI. Thank you very much, Mr. Chairman. I am honored to be invited to take part in these hearings.

Let me begin by noting that earthquake hazard in the United States is a national problem. We know that damaging earthquakes occur frequently enough in the Western States, including Hawaii and Alaska, to remind everybody of their threat. Also, in many cases, their fault rupture lines, like the San Andreas Fault, the Calaveras Fault or the Hayward Fault, are very conspicuous on the earth's surface. This tends to make people conscious of their existence.

But in the eastern two-thirds of the country, earthquakes occur less frequently, and the faults that produce them cannot be seen at the surface. Therefore, the earthquakes are a hidden threat, although they are a very real one. Even though every Eastern State has not had a damaging earthquake within its borders, as Congressman Brown pointed out, there were 39 States that had had damaging earthquakes, and all of the States can and will experience earthquake damage in the future. The reason is that earthquake wave energy undergoes less attenuation in the East and, therefore, damage occurs as far as several hundred miles away from a moderately large earthquake.

Now, the very large earthquakes have occurred in the St. Lawrence Valley of southern Canada, which is just north of the New England States, in the 17th century, and in the central Mississippi Valley, the so-called New Madrid earthquakes, in the early 19th century, and at Charleston, SC in the latter part of the 19th century.

In addition, moderately large earthquakes have happened in Massachusetts, New Hampshire, New York, Virginia, South Carolina, Ohio, Illinois, Kentucky, Tennessee, Arkansas, Nebraska, Missouri, Oklahoma, Kansas, and Texas since the time of settlement. Earthquakes which approach the level of damage, such as the recent one near Lancaster, PA; have occurred in almost all of the

Eastern States. They indicate that the potential for damage is everywhere present.

Research support from the National Science Foundation, the U.S. Geological Survey, and the U.S. Nuclear Regulatory Commission for about the past 10 years has given us the beginning of a data base that is needed for Eastern United States earthquake studies. Information that is critically needed includes the identification and location of the active faults or the source zones, the recurrence time of earthquakes of a given magnitude for each zone, the attenuation of wave energy from the source zone, the size of the maximum possible earthquake in each zone, and also recordings of strong ground motion near the earthquake.

All of these, except the strong motion data, are provided by seismic networks. It is essential that the presently existing networks of the East continue to operate on a long-term basis if we are to obtain the data needed to ensure that critical structures and facilities are designed both safely and economically. I might emphasize that last word, "economically," too, because we can overdesign buildings if we don't know the risks too well.

The present distribution of strong motion instruments in the East is inadequate for both seismological and engineering purposes. We badly need close-in data from a large earthquake in the East. Because these earthquakes occur relatively infrequently, we should instrument all of the potential places where we believe they might occur, to be certain not to miss such essential data. Also, I would like to see a few strong motion instruments in the basements and the upper levels of very tall buildings in all the large eastern metropolitan areas. My research indicates that strong shaking at upper levels can be expected as far away as 500 miles from a moderately large earthquake.

I have been asked to say a few words about the New Madrid Fault in the central Mississippi Valley. It is the most active fault system in the Eastern United States. The St. Louis University seismograph network detects and locates about one earthquake every 2 days from that fault. There are on average about five earthquakes per year large enough to be felt by people. The moderately large earthquakes, of magnitude of 6 to 6½, occur on average once every 75 to 100 years. The most recent ones happened in 1843 and 1895.

The 1843 earthquake was near the southern end of the fault, and did considerable damage in Memphis as well as in northern Mississippi and in eastern Arkansas where the epicenter was located. The 1895 earthquake had its epicenter in southern Missouri, where it did damage. Also, it did damage in southern Illinois and as far away as St. Louis.

From my studies of the New Madrid earthquake, I believe the fault presently has enough energy stored up to produce a magnitude 7.6 earthquake. Only two 20th century U.S. earthquakes have had larger magnitudes, the San Francisco earthquake of 1906 and Alaskan earthquake of 1964. Earthquakes of magnitude of 7.6 caused 10,000 deaths in Italy in 1980, and at least 250,000 deaths in China in 1976.

Now, I want to emphasize that we cannot predict the time of occurrence of the next very large New Madrid earthquake. If it were to occur today, it would be of magnitude of about 7.6. But it may

not happen for many decades, or even perhaps for centuries. The longer the wait, the bigger the earthquake is going to be. And while we wait for it, we are going to see moderately large earthquakes of magnitude about 6 to 6½ occurring every 75 to 100 years.

In my opinion, earthquake prediction in the Eastern United States will lag behind prediction in the Western States. Our earthquakes occur less frequently, the active faults cannot be instrumented at the surface, and we know less about the causative process. But we have learned, and are continuing to learn more, so that we have the knowledge to make buildings and critical facilities much safer. We can begin to make plans also for emergency response to such a great natural disaster.

I thank you, Mr. Chairman, for giving me the opportunity to appear at the joint hearing of the subcommittees, and I would be glad to answer any questions you or members of the subcommittees might have.

Mr. GORE. Thank you very much, and we are looking forward to asking several questions. But before we do so, we want to hear all members of the panel and then address questions to the panel.

[The prepared statement of Dr. Nuttli follows:]

STATEMENT BY OTTO W. NUTTLI, REINERT PROFESSOR IN THE SCIENCES OF SAINT LOUIS
UNIVERSITY

Earthquake hazard in the United States is a national problem. Damaging earthquakes occur frequently enough in the western states, including Hawaii and Alaska, to remind everyone of their threat. Also in many cases their fault rupture line is conspicuous on the earth's surface, which tends to make people very conscious of their existence. In the eastern two-thirds of the country earthquakes occur less frequently, and the faults that produce them cannot be seen at the surface. Thus the earthquakes are a hidden threat, although a very real one. Even though every eastern state has not had the epicenter of a damaging earthquake within its borders, all can and will experience earthquake damage. The reason is that earthquake wave energy undergoes less attenuation in the East, and therefore damage occurs as far as several hundred miles away from a moderately large earthquake.

Very large earthquakes occurred in the St. Lawrence valley of Canada (just north of New England states) in the 17th century and in the central Mississippi valley and in South Carolina in the 19th century. Moderately large earthquakes have occurred in Massachusetts, New Hampshire, New York, Virginia, South Carolina, Ohio, Illinois, Kentucky, Tennessee, Arkansas, Nebraska, Missouri, Oklahoma, Kansas and Texas since the time of settlement. Earthquakes approaching the level of damage, such as the recent one near Lancaster, Pennsylvania, have occurred in almost all the eastern states. They indicate that the potential for damage is everywhere present.

Research support from the National Science Foundation, the U. S. Geological Survey and the Nuclear Regulatory Commission for about the past ten years has given us the beginning of a data base that is needed for eastern United States earthquake studies. Information that is critically needed includes the identification and location of active faults or source zones, the recurrence time of earthquakes of a given magnitude for each zone, the attenuation of wave energy

from the source zone, the size of the maximum possible earthquake in each source zone, and recordings of strong ground motion near the earthquake. All except the strong-motion data are provided by seismic networks. It is essential that the presently existing seismograph networks of the East continue to operate on a long-term basis, if we are to obtain the data needed to ensure that critical structures and facilities are designed both safely and economically. The present distribution of strong-motion instruments in the East is inadequate for both seismological and engineering purposes. We badly need close-in data from a large earthquake in the East. Because such earthquakes occur relatively infrequently, we should instrument all the potential places where we believe they might occur, to be certain not to miss such essential data. Also, I would like to see a few strong motion instruments in basements and at the upper level of very tall buildings in all the large eastern metropolitan areas. My research indicates that strong shaking at upper levels can be expected as far away as 500 miles from a moderately large earthquake.

Let me say a few words about the New Madrid fault in the central Mississippi valley. It is the most active fault system in the eastern United States. The Saint Louis University seismograph network detects and locates about one earthquake every two days from that fault. There are on average about five earthquakes per year that are large enough to be felt by people. Moderately large earthquakes, of magnitude 6 to $6\frac{1}{2}$, occur on average about once every 75 to 100 years. The most recent ones of that size occurred in 1843 and 1895. The 1843 earthquake was near the southern end of the fault, and did appreciable damage in Memphis, as well as in northern Mississippi and in eastern Arkansas, where it was located. The 1895 earthquake occurred in southern Missouri. It also caused damage in southern Illinois and as far away as St. Louis. From my studies

of the New Madrid earthquake, I believe the fault presently has enough energy stored up to produce a magnitude 7.6 earthquake. Only two 20th century United States earthquakes have had larger magnitudes, the San Francisco earthquake of 1906 and the Alaskan earthquake of 1964. Earthquakes of magnitude about 7.6 caused 10,000 deaths in Italy in 1980 and at least 250,000 deaths in China in 1976.

I wish to emphasize that I cannot predict the time of occurrence of the next very large New Madrid earthquake. If it were to occur today, it would be of magnitude 7.6. But it may not happen for many decades, or perhaps even centuries. The longer the wait, the bigger the earthquake will be. And, while we wait for it, we will see moderately large earthquakes of magnitude about 6 to $6\frac{1}{2}$ occurring every 75 to 100 years.

In my opinion earthquake prediction in the eastern United States will lag behind prediction in the western states. Our earthquakes occur less frequently, the active faults cannot be instrumented at the surface, and we know less about the causative processes. But we have learned, and are continuing to learn more, so that we have the knowledge to make buildings and critical facilities much safer, and we can begin to make plans for emergency response to such a great natural disaster.

Thank you, Mister Chairmen, for giving me the opportunity to appear at the joint hearing of your Subcommittees.

BIOGRAPHICAL SKETCH

Otto W. Nuttli is Professor of Geophysics at Saint Louis University. He received B.S., M.S. and Ph.D. degrees in geophysics from Saint Louis University, and has been a member of its faculty since 1952. He is a fellow of the American Geophysical Union and is a member of the Seismological Society of America, the Earthquake Engineering Research Institute, the Society of Exploration Geophysicists and the Royal Astronomical Society. He has served as president of the Seismological Society of America, as editor of the Bulletin of the Seismological Society of America, and as an associate editor of the Journal of Geophysical Research. His principal fields of research are seismology and earthquake engineering, with emphasis on the eastern United States.

Mr. GORE. Our next witness is Dr. Arch C. Johnston, director of the Tennessee Earthquake Information Center at Memphis State University in Memphis, TN.

Dr. Johnston, it is a particular pleasure for me to welcome a fellow Tennessean here. I want to thank you for the tour of your Earthquake Information Center last week, an impressive facility, and the work that you all are doing there is giving us, as a country, a big head start in our efforts to deal with Eastern earthquakes. And, without further ado, I want you to proceed with your statement.

Hold on 1 second here. OK. We have a vote on the floor right now. Why don't we—this would be a natural breaking point. Why don't we, if you will bear with us for about 6 to 8 minutes, rather than interrupting you in the middle of your statement, we will go over and vote now, and then come right back. We will adjourn—recess rather, for about 8 minutes and come back.

[Recess.]

Mr. GORE. If the subcommittees would come back to order, please, let's crank up the hearing.

We were just about to hear from Dr. Arch Johnston, director of the Tennessee Earthquake Information Center. I'm sorry that a vote on the floor delayed your testimony. We're glad to hear it now, so please proceed.

Dr. JOHNSTON. Thank you, Mr. Chairman. I would like to express my appreciation to both subcommittees for the opportunity to testify today.

We are not going to solve the problems associated with Eastern U.S. earthquakes in 1 day, but it's through efforts such as this

hearing that we can make a lot of progress. These efforts will not be for naught; they will pay dividends.

Mr. GORE. If you could bend that microphone down a bit closer to you, I think we will—

Dr. JOHNSTON. All right. Is this better?

Mr. GORE. Yes, it sure is.

Dr. JOHNSTON. These efforts will pay dividends, if not to our own, then to future generations of Americans.

I will keep my remarks brief because of today's full agenda. I would like to say a few words about the overall problem of Eastern U.S. earthquakes, and then address a few specific resource topics.

Seismologists do not differ from scientists of other disciplines in that they need observational data of high quality on which to base theories of how earthquakes are generated, what conditions are necessary to produce earthquakes, and what effects can be expected from earthquake occurrence. These data are more difficult to obtain in seismology than most other sciences. Earthquakes are transient phenomena. They occur at inaccessible depths in the crust, and are scattered in space and time. A seismologist does not have the luxury of taking an earthquake back to the laboratory for later study.

These difficulties that are inherent in fundamental earthquake research are compounded in the Eastern United States. By that, I mean East of the Rocky Mountains. In the West, the association of earthquakes with geologically prominent fault systems is very strong. In the East, however, active faulting is either not occurring or occurring at much slower rates than in the West, and the choice of the best use of limited research resources is much more difficult. Most Eastern U.S. seismic activity is apparently a response of ancient fault structures to present-day stress regime in the Earth's crust. This reactivation process is more sporadic, less predictable, and much less well understood than the active faulting in the West.

A useful way of looking at this difference between Western and Eastern U.S. seismicity is to go through the process of estimating the 1,000-year earthquake for the two regions. That is, what is the largest magnitude event that can reasonably be expected to occur in any 1,000-year time interval. For the West, attention can focus on the great plate boundary fault, the San Andreas, even though large earthquakes can and will occur in other zones. Various recent estimates for the San Andreas—various recent recurrence estimates for magnitude 8 on the San Andreas place it at about 140, plus or minus about 60 years. Thus, in a 1,000-year period, one can be virtually certain that a quake of magnitude greater than 8 will occur. Moreover, fairly good estimates of specific sites for such a quake are possible.

In the Eastern United States, however, such recurrence and site-specific estimates are fraught with uncertainty. The so-called New Madrid seismic zone spanning portions of the Missouri bootheel, northwest Tennessee and northeast Arkansas, is considered the most dangerous seismic zone in the East. Through the pioneering work of Dr. Nuttli, we have reliable estimates that the magnitudes of the three New Madrid events in 1811 and 1812 exceed magnitude 8.

But what is the recurrence? Estimates by myself and others have ranged from 500 to more than 1,800 years. Such very long recurrence estimates raise the spectre of other seismic zones in the East that could be capable of great earthquakes that are unknown to us because of the very long repeat times between great earthquakes. Suppose such zones failed well before Europeans settled North America. Their potential for a destructive earthquake could now be quite high, and our knowledge of their existence—we would have no knowledge of their existence.

This situation leads naturally to significant differences in the approach for research, seismic research, in the Eastern and Western United States. The West, with its well-defined fault systems and high level of seismic activity, is the best place to study fundamental source properties of earthquakes, and also to study earthquake precursors for prediction purposes. And this is true simply because of the large number of quakes in the West and the relatively well known seismic zones, so that if you deploy an instrument, then that instrument has a much greater chance of collecting significant data than a similar instrument in the East. The emphasis in the East, I feel, should be of a different nature. The overriding concern here is to delineate or define the seismic zones and assign properties to them, such as seismic activity rate and the maximum expected earthquake. So this type of research is to recover information that is already fairly well known in the West.

In summary, our current state of knowledge in the East is very limited as concerns a number of critical questions. Some of these are, what type of geologic structures have the potential to produce large earthquakes? A corollary to this is, is there a class of structures that we can exclude from such a possibility? Does the age, the thermal state, the type of rock or the orientation of the structure play a role and, if so, how critical? How good a guide to future seismicity is our knowledge of the past historical record of earthquake activity, when that record is incomplete and it spans only 200 to 300 years, and large destructive earthquakes may have a recurrence time of over 1,000 years?

Also, how good a guide to future activity is the past 10 to 15 years of high-quality microearthquake data that we collect from our instrument monitoring networks? Another way to phrase this question would be, can large earthquakes occur in regions that do not exhibit a low level of microearthquake activity? What factors limit the size of the maximum possible earthquake in the seismic zones in the East that we do know? What are the expected ground motions in terms of amplitude and frequency of large destructive earthquakes in the East? Currently, we must estimate these motions mainly from California data. These are some of the fundamental questions for earthquake research in the East.

I would like to mention very briefly now two research approaches, current research approaches, and suggest some things we need to do for the future.

The first is earthquake monitoring networks. These seismic networks and their associated support, mainly computer support, are probably the single most expensive item in basic seismological research in the East. The stations need to be located in remote areas and distributed over broad regions. The continuous data stream is

transmitted back to seismic centers via radio or telephone for recording and analysis. An example of this type of regional instrument monitoring, the Tennessee Earthquake Information Center, operates two networks spread out over seven States, and they cost roughly \$200,000 per year to keep in continuous operation.

Are the networks worth it? They come under close scrutiny each year because of the high associated costs. Some, at present, monitor areas of very low seismic activity. Yet, as Dr. Nuttli has said and I would like to emphasize, they have proved their worth again and again in the past, and I believe it would be a serious mistake to reduce or curtail their operation now.

An example of their value is to look at the situation for the New Madrid seismic zone. Just in the past 10 years, since the U.S. Geological Survey funded the St. Louis University network, prior to that, the zone was known only as the rather diffused blob of earthquake epicenters. The network data quickly sharpened the resolution, specific fault centers were identified, an elevated rate of microearthquake activity was recorded, and these basic data inspired very successful geological, geophysical investigations of the New Madrid zone by the U.S. Geological Survey and the Nuclear Regulatory Commission. Other seismologists, including myself, routinely use the data produced by the networks in our research.

Also, networks have delineated seismic zones in Virginia, the Giles County area, and very recent results obtained by the Tennessee Earthquake Information Center in the southern Appalachians of southeast Tennessee.

So, seismic networks have proven to be the single best weapon we have for the definition of seismic zones in the East. Their data product is extremely relevant to questions of siting and design of critical facilities, such as nuclear power generating plants or nuclear waste repositories. Their data accumulation rate is low in the East because the seismic activity rate is low. Therefore, seismic networks need to be viewed as essentially permanent research tools with lifetimes measured in decades, not in years.

The second category of instruments that I feel is extremely important in the East is strong ground motion instrumentation. These are triggered instruments that record only when strong ground motion occurs from large earthquakes.

In the East, again echoing Dr. Nuttli, no actual instrumental recordings exist of strong ground motion close to a large earthquake. This fact hampers efforts to provide safe and realistic seismic design criteria for buildings and lifelines in the East.

Extrapolation of California data involves two major uncertainties. The first relates to the much greater attenuation of seismic wave energy in the West than in the East; and the second is that the source characteristics of Eastern U.S. earthquakes are quite different from those in the West.

Attempts have been made to model these effects, but a critical need exists to obtain actual instrumental records. The only approach to this is to deploy a large number of strong motion recorders so that a large earthquake, when it occurs, will be captured, so to speak. At present, strong motion instrumentation in the East lags far behind that in the West. The value of Eastern strong motion records to the engineering community, however, creates a

strong argument for sharply increased strong motion instrumentation.

Now, to summarize, I would like to make two general observations for Eastern U.S. earthquake research. The first is that the seismological research community is becoming increasingly organized on a national scale, much in the manner of high-energy physics, astronomy or meteorology. However, an essential ingredient in seismology will always be the locally based research organization—and this is usually university-based—that can continue with long baseline data collection and analysis and provide a local means of support for national and/or global programs. The health and vigor of the seismological research effort depends on the health and vigor of these local units.

Second, estimates have been made of the devastation occurring from a maximum-magnitude earthquake in a populated region in the Eastern United States. The effects have been compared to the effects of a nuclear war. Because of the large area of structural and architectural damage and the attendant casualties in such an earthquake, this comparison is a valid one, of course, leaving aside the long-term radiological and climatological effects accompanying a nuclear exchange.

I believe one important aspect of this comparison has been overlooked. The fatalistic viewpoints notwithstanding, the occurrence of nuclear war is not a certainty. We plan and prepare for the eventuality, but it may not happen. The same statement is not true about a major destructive earthquake. Possibly within our lifetime, possibly many generations from now, a large destructive earthquake will occur in the Eastern United States. The New Madrid seismic zone is the most likely site, but we cannot exclude the possibility of other locations. Thus, any research, any response and mitigation efforts we engage in now will not be wasted. They are going to pay dividends either for our or future generations.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Johnston, plus attachments, follow:]

Testimony Before the Subcommittee on Investigations
and Oversight and the Subcommittee on Science, Research
and Technology of the U.S. House of Representatives
Committee on Science and Technology

By Dr. Arch C. Johnston, Director
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Memphis State University
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May 23, 1984

I would like to express my appreciation to both subcommittees for the opportunity to testify today. We are not going to solve the problems associated with Eastern U.S. earthquakes in one day, but it is through efforts such as this hearing that we can implement a responsible and well-designed program of research, mitigation and response planning. These efforts will not be for naught; they will pay dividends, if not to our own then to future generations of Americans.

I intend to keep my remarks brief because of the full agenda of today's session, but I want to say a few words about the overall problem of eastern U.S. earthquakes--problems both from research and disaster planning viewpoints--before addressing a few specific research topics in which I have been particularly involved.

Seismologists do not differ from scientists of other disciplines in that they need observational data of high quality on which to base theories of how

earthquakes are generated, what conditions are necessary to produce earthquakes, and what effects can be expected from earthquake occurrence. However, such data are more difficult to obtain in seismology than in most other sciences: earthquakes are transient phenomena, they originate at inaccessible depths in the crust and are scattered in space and time. A seismologist does not have the luxury of taking an earthquake back to the laboratory for later study.

These difficulties, inherent in fundamental earthquake research, are compounded in the Eastern United States (east of the Rocky Mountains). In the West the association of earthquakes with geologically prominent fault systems is very strong; a clear rationale for deployment of expensive instrument networks is possible. In the East, however, where active faulting is either not occurring or occurring at much slower rates than in the West, the choice of the best use of limited research resources is much more difficult. Most Eastern U.S. seismic activity is apparently a response of old fault structures to the present-day stress regime of the crust. This reactivation process is more sporadic, less predictable and much less well understood than the active faulting in the West.

One useful way of looking at the dichotomy between western and eastern U.S. seismicity is go through the process of estimating the 1000-year earthquake for the two regions. That is, what is the largest magnitude event that can reasonably be expected to occur in any thousand-year time interval? For the West, attention can focus on the great plate boundary fault, the San Andreas, even though large earthquakes can and will occur in other zones. Various recent estimates have placed the recurrence time of great earthquakes on the San Andreas (magnitude >8.0) at about 140 ± 60 years. Thus in a 1000-year period one can be virtually certain that a quake of about magnitude

8 1/2 will have occurred. Moreover, fairly good estimates of specific sites for such quakes are possible.

In the Eastern U.S., however, such recurrence and site-specific estimates are fraught with uncertainty. The so-called New Madrid seismic zone spanning portions of the Missouri bootheel, NW Tennessee and NE Arkansas is considered the most dangerous seismic zone in the East. Through the pioneering work of Dr. Nuttli of Saint Louis University we have reliable estimates that the magnitudes of three New Madrid events in 1811-1812 exceeded magnitude 8. But what is the recurrence? Estimates by myself and others have ranged from 500 to more than 1800 years. Such very long recurrence estimates raise the spectre of other seismic zones in the East, capable of great earthquakes, that are unknown to us because of very long repeat times between great earthquakes. If such zones last failed well before Europeans settled North America, their potential for a destructive earthquake could be very high and our knowledge of the existence of these zones could be nonexistent.

The situation I have described above leads naturally to some significant differences in the research approach for the Eastern and Western U.S. The West, with its well-defined fault systems and high level of seismic activity, is the best place to study fundamental source properties of earthquakes and earthquake precursors for prediction purposes. This is true simply because the large number of quakes and the relatively well known seismic zones means that a deployed instrument has a greater chance of collecting significant data than a similar instrument in the East. The research emphasis should be of a much different nature in the East. The overriding concern here is to define seismic zones and assign properties to them such as seismic activity rate and the maximum expected earthquake.

In summary, our current state of knowledge in the Eastern U.S. is very

limited as concerns such critical questions as:

- What types of geological crustal structures or geophysical anomalies have the potential to produce large earthquakes? Is there a class of structures that we can exclude?
- Does the age, the thermal regime, the type of crustal rock, or the orientation of the structural feature(s) play a role, and if so how critical?
- How good a guide to future seismicity is our (incomplete) knowledge of the past record of historical earthquake activity, when that record spans only 200-300 years and a recurrence time of >1000 years for some zones must be admitted as a possibility?
- How good a guide to future activity is the past 10-15 years of high quality microearthquake data gathered from the instrument monitoring networks installed in some regions? (Another way to phrase this question is "can large earthquakes occur in regions that do not exhibit a low level of microearthquake activity?"
- What are the parameters that limit the size of the maximum possible earthquake in known seismic zones?
- What are the expected ground motions in terms of amplitude and frequency of large, destructive quakes in the East? (Currently we must estimate this from California data.)

These are some of the questions that earthquake research in the Eastern U.S. must address. I would next like to briefly examine some aspects of the current research effort and suggest some approaches for the future that I believe to be the most productive in seeking answers to the questions posed above.

EARTHQUAKE MONITORING NETWORKS. Seismic networks and their associated support computers are probably the single most expensive item in basic seismological research in the East. The stations need to be located in remote areas removed from human activity and distributed over broad regions. The continuous data stream is transmitted back to seismic centers via radio or leased

telephone line for recording and analysis. As an example of this regional monitoring, the Tennessee Earthquake Information Center operates two networks funded by the Nuclear Regulatory Commission. These comprise some 25 stations spread out over seven states and cost about \$200,000 per year to keep in continuous operation and reduce and analyze the data.

Are the networks worth it? They come under close scrutiny each year because of the high associated costs. Some at present monitor essentially aseismic regions or regions of very low background activity. Yet they have proved their worth again and again in the past and I believe it would be a serious mistake to reduce or curtail their operation now. One need only examine the exceptional progress made in the delineation and understanding of the New Madrid seismic zone in the past 10 years. When the USGS/St. Louis Univ. network was installed in 1974, the zone was known only as a diffuse blob of earthquake epicenters. The network sharpened the resolution so that specific fault segments were identified, it clearly showed an elevated rate of microquake activity and it inspired very successful geological and geophysical investigations of the zone by the USGS and NRC that have defined the geological evolution and crustal structure of the zone in impressive detail. (A summary article of this research, "A Major Earthquake Zone on the Mississippi", Scientific American, Vol. 246, p.60-68, April, 1982, by A.C. Johnston, is included as an Appendix to this testimony.) Other seismologists, including myself, routinely use the data produced by this network in their research. Similar examples of seismic networks leading to useful delineations of seismic zones are the Giles County zone in Virginia by VPI & SU and very recent results obtained by TEIC for the southern Appalachians in southeast Tennessee.

Seismic networks have proved to be the single best weapon we have for the definition of seismic zones in the East. Their data product is thus extremely

relevant to questions of siting and design of critical facilities such as nuclear power generating plants or nuclear waste repositories. Their data accumulation rate is low because the seismic activity of the East is low. Therefore seismic networks need to be viewed as essentially permanent research tools with lifetimes measured in decades, not in years.

STRONG GROUND MOTION INSTRUMENTATION. No actual instrumental recordings exist of strong ground motion close to a large Eastern U.S. earthquake. This fact hampers efforts to provide safe and realistic seismic design criteria for buildings and lifelines in the East. Extrapolation of California data involves two major uncertainties: the first relates to the much greater attenuation of seismic wave energy in the West and the second relates to the difference in source characteristics between eastern and western quakes. Studies by Dr. Nuttli and others indicate that major Eastern U.S. quakes, when compared with western events, can be expected to result in elevated levels of high frequency ground vibration close to the epicenter and stronger low frequency vibrations of longer duration at large distances from the event.

Attempts have been made to model the above effects, but a critical need exists to obtain actual instrumental records. This only can be done by deploying large numbers of strong motion recorders (instruments that trigger only on strong ground motion) and waiting to "capture" a large earthquake. At present strong motion instrumentation in the East lags far behind that in the West because of the lower incidence of large eastern earthquakes. The value of eastern strong ground motion records to the engineering community, however, creates a strong argument for sharply increased strong motion instrumentation, even if any single instrument has a low probability of being triggered.

MAJOR NATIONAL OR GLOBAL-SCALE PROGRAMS. There are a number of major initiatives in seismology today that will have significant impact on earthquake research in the Eastern U.S. I will allude to these only briefly because I think they will be examined in greater detail in other testimony at these hearings.

(1) The Global Digital Network (GDN). One of the primary objectives of the newly-formed Incorporated Research Institutions for Seismology (IRIS), the GDN is designed to replace the 1960's vintage Worldwide Standard Seismograph Network with state-of-the-art digital stations. Siting a number of GDN stations (4-6) and at least one regional data center in the Eastern U.S. would provide a needed long-term basis of support to various research groups in the region and also provide access to the most modern digital techniques.

(2) Program for Array Seismic Studies of the Continental Lithosphere (PASSCL). This program is also a part of the IRIS program and has the potential of providing a quantum jump in our understanding of Eastern U.S. seismic zones. Under PASSCL large arrays of broadband digital instruments would be deployed over broad regions to provide data on the structure and properties of the crust and upper mantle with a detail and resolution heretofore unattainable. The importance of PASSCL to seismic studies in the East cannot be overstated.

(3) Deep drilling of the continental crust. Many questions relating to rock properties, thermal and stress regime and geological evolution of the continental crust at the depths at which earthquakes occur will only be definitively answered by deep continental drilling. The reason this has not yet been done is that it is very expensive. However, a national program of deep continental drilling should be a long-range research goal of the earthquake hazards program.

There are many other current and future research goals and accomplishments that I could discuss; I have mentioned the ones that I consider the most important and others I'm sure will be covered elsewhere in these hearings. I would like to conclude with two general observations that relate to research in the East.

(1) The seismological research community is becoming increasingly organized on a national scale much in the manner of high energy physics, astronomy or meteorology. However, an essential ingredient in seismology will always be the locally-based research organization (usually university-based) that can continue long baseline data collection and analysis and provide a local base for national and/or global programs. The health and vigor of the seismological research effort depends on the health and vigor of these local units.

(2) The devastation wrought by a maximum magnitude earthquake in a populated region of the Eastern U.S. has been compared to the effects of a nuclear war. Because of the large area of structural and architectural damage from such a quake, the comparison is a valid one, leaving aside the long-term radiological and climatological effects accompanying a nuclear exchange. However, I believe one very important aspect of this comparison has been overlooked. Fatalistic viewpoints notwithstanding, the occurrence of nuclear war is not a certainty. We plan and prepare for the eventuality, but it may not happen. The same statement is not true about a major destructive earthquake. Possibly within our lifetime, possibly many generations from now, a large destructive earthquake will occur in the Eastern United States. The New Madrid seismic zone is its most likely site, but we cannot exclude the possibility of other locations. Thus any research, any response and mitigation efforts we engage in now and in the future will not be wasted. They are going to pay dividends either for our or for future generations.

960
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by Arch C. Johnston

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A Major Earthquake Zone on the Mississippi

Three of the strongest quakes in U.S. history were not in the West but in New Madrid, Mo. They came in 1811 and 1812, and even now the area is shaken by an average of one small quake every other day

by Arch C. Johnston

At the mention of earthquakes most Americans think of the great San Francisco earthquake of 1906 and the continuing threat to California represented by the San Andreas fault. The fact is that three of the greatest earthquakes in American history occurred 170 years ago not on the Pacific coast but near a placid meander loop of the Mississippi River where the states of Kentucky and Missouri meet. On December 16, 1811, and again on January 23 and February 7, 1812, the river region was struck by earthquakes with respective estimated magnitudes of 8.6, 8.4 and 8.7. The tremors were felt throughout the northeastern U.S. and parts of Canada. They cracked plaster in Richmond, Va., and rang church bells and cracked pavements in the District of Columbia. To this day the region, in the vicinity of New Madrid, Mo., remains seismically active; indeed, it is shaken by small earthquakes on an average of every 48 hours. Why should an area in the middle of the continent be so susceptible to earthquakes? Some decades of research have led to the surprising conclusion that here, near the northern apex of what geologists call the Mississippi embayment, there is a rift in the continental craton: that part of the great North American plate consisting of the oldest and strongest rock in the continental crust. This ancient rift has been reactivated by tectonic forces.

The Mississippi embayment is a wide U-shaped expanse bisected by the river. It begins near the confluence of the Ohio and Mississippi rivers and widens southward into the Gulf of Mexico coastal plain. To the east of the Mississippi are gently rolling hills capped by deposits of loess (windblown silt), an indication that the river never flowed there. To a traveler in the western part of the embayment its most arresting feature is its unyielding flatness. Here sand and gravel terraces, natural levees, drainage divides and abandoned meander loops all testify to the fact that the

river often wandered far to the west of its present course.

The town of New Madrid lies on the north bank of a Mississippi meander loop known as the Kentucky Bend. It was founded late in the 18th century (in what was then Spanish territory) with the intent of establishing a trade center for the barge and flatboat traffic on the river. By early in the 19th century its hundreds of inhabitants made New Madrid the largest settlement in the region. Thus the town lent its name to the extraordinary events of 1811 and 1812.

The three massive earthquakes that winter were each followed by a protracted series of strong aftershocks. The effects were awesome. The saturated bottomland soil spurted huge geysers of sand and water. During the main shocks the land heaved and buckled for minutes, trees were splintered, a prolonged roaring was heard and the air smelled of sulfur. According to one account, the aftershocks were a constant trembling, "like the flesh of a beef just killed."

The effect of the third and strongest main shock on the Mississippi itself was even more striking. As an eyewitness wrote, at "about 4 o'clock A.M. a concussion took place so much more violent than those which preceded it that it was denominated the hard shock.... At first the Mississippi seemed to recede from its banks... its waters gathering up like a mountain [only to fall] again with such violence that it took with it whole groves of young cotton wood trees which ledged its borders.... The river was literally covered with the wreckage of boats." The riverbed itself was so dis-

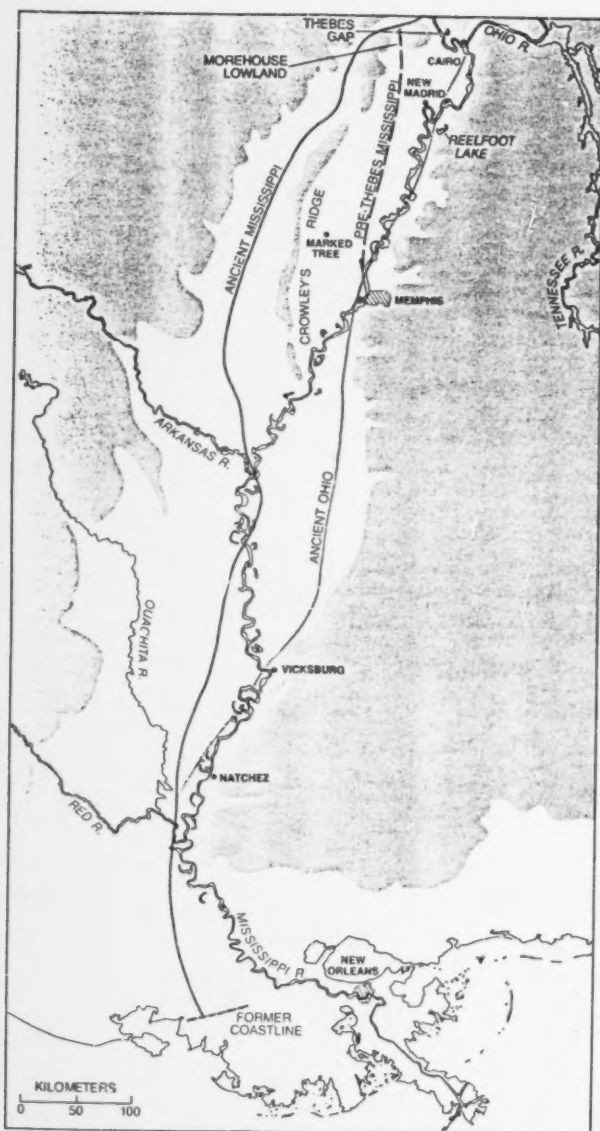
turbed that two waterfalls (or at least rapids) were formed, one upstream from New Madrid and one downstream.

The recent geological history of the Mississippi embayment is closely related to the last of the great glacial advances of the Pleistocene, which in North America ended some 8,000 years ago. At its maximum this advance—the Wisconsin glaciation—covered much of the north-central U.S., extending as far south as southern Illinois. So much water was locked up in the vast ice sheets of the Wisconsin period that the level of the sea was 60 to 80 meters lower than it is today, and most of the continental shelves were dry land. Rivers to the north of the Ohio and the Missouri, which formerly flowed north into Hudson Bay and the St. Lawrence River, were blocked by the ice and were diverted south, augmenting the Mississippi drainage system.

The lowered level of the Gulf of Mexico meant a steeper gradient for the south-flowing rivers. This factor and others (such as flooding) caused both the Mississippi and the Ohio (which then did not join the Mississippi until it reached the vicinity of modern Natchez) to cut deepened valleys through the Mississippi embayment. By the time the Mississippi reached the edge of the continental shelf its channel was more than 100 meters deeper than it is today. The melting of the glaciers brought a rise in the sea level and the release of huge amounts of glacial debris, so that the deeply entrenched river valleys were soon filled with alluvial sediments.

VICINITY OF NEW MADRID is seen in false color in the aerial photograph on the opposite page, part of a survey conducted by the National Aeronautics and Space Administration on behalf of the U.S. Army Corps of Engineers. The Mississippi meander at the far left is the Kentucky Bend; part of the town of New Madrid is visible on the river's north bank. The time is fall and some of the farm fields that make up the rectangular patterns on the fertile bottomland have been cleared of crops (vegetation appears red). At the lower-right corner is the northeastern end of Reelfoot Lake, a Tennessee landmark. A map including the area shown in the photograph (which covers part of the Lake County uplift, a seismic zone) appears on page 6.





PRESENT COURSES of the Mississippi and the Ohio, which now meet near Cairo, Ill., are much different from the courses of late Pleistocene times. The Ohio (light color) did not join the Mississippi until it reached the vicinity of modern Natchez, and the Mississippi (dark color) ran well to the west of its present course for most of its length. The later Morehouse diversion (broken colored line) then brought the two rivers together near modern Memphis, rather than below Thebes Gap as at present. Gray areas to the east and west approximate the 250-foot contour line. The low area between the Tennessee River and the western contour line is known as the Mississippi embayment. It widens into the Gulf coastal plain. Crowley's Ridge is the by-product of valley widening and erosion by the ancient rivers on both its east and west flanks.

In the 1940's Harold N. Fisk of the U.S. Army Corps of Engineers established a remarkable fact about the Mississippi-Ohio system in late Pleistocene times, some 18,000 years ago. The valley of the Mississippi, Fisk found, was then far to the west of the river's present channel, and the valley of the Ohio passed through what is now eastern Arkansas and western Mississippi. After the retreat of the Wisconsin ice the Mississippi channel was diverted eastward from the western lowlands of the Mississippi embayment until finally it ran through a narrow pass at the apex of the embayment that is today called Thebes Gap.

What caused such a drastic shift in the channel? Fisk considered two possibilities: a gradual deepening of Thebes Gap by periodic erosion during floods and a headward erosion of a tributary of the Ohio that finally resulted in the "capture" of the Mississippi. A third possibility is that the Thebes Gap diversion was tectonic, specifically the result of faulting.

There is little doubt that tectonic influences have controlled the course of the Mississippi in certain places. An example is found in Lake County, Tenn., in the heart of the New Madrid seismic zone. In 1974 Saint Louis University, with support from the U.S. Geological Survey, installed a network of modern seismic instruments in the New Madrid zone. It was augmented in 1979 by the installation of a second network by Memphis State University, with support from the Nuclear Regulatory Commission. The second network is operated by the university's Tennessee Earthquake Information Center. The New Madrid zone is monitored 24 hours per day, and the networks can detect and locate disturbances as small as magnitude 1.0 (an energy release equivalent to the impact of a two-ton weight dropped 12 feet).

Some 700 square kilometers in Lake County are uplifted; the central portion of the zone is from three to 10 meters higher than the surrounding region. This may at first seem insignificant, but it is hard to explain such an uplifted surface in the middle of a level river floodplain. The readings of the seismic network show that the uplifted area overlies the part of the New Madrid seismic zone where the earthquake activity is most intense. Most of the events are microquakes, with magnitudes of less than 2.5 (roughly the threshold of human perception). David P. Russ of the Geological Survey, who has studied the Lake County uplift, considers it responsible for the deflection of the Mississippi channel to the west between Hickman, Ky., and Caruthersville, Mo. He points to anomalous river gradients and channel geometries in the area, and he views the uplift as a surficial response to movement on deep-seated faults. The fact that the area coincides geographi-

tally with the zone of intense microquake activity suggests that most of the fault movement is seismic, that is, a sudden displacement that generates seismic waves rather than a gradual release of accumulated crustal strain.

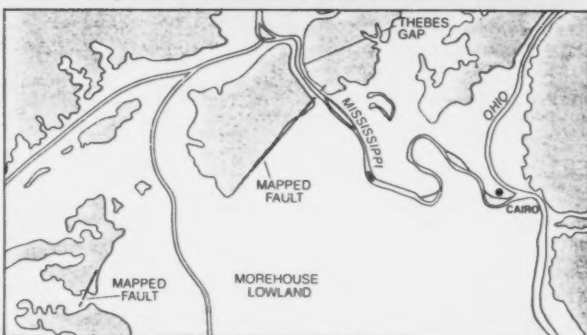
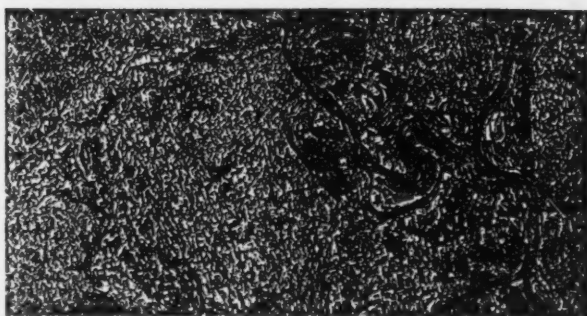
If the Hickman deflection is a product of recent tectonic influences, might not the Thebes Gap diversion be the result of older ones? The gap is about 30 kilometers north of New Madrid. Although the area is not now associated with any marked concentration of microquakes, numerous faults have been mapped in it. Pending further studies such a hypothesis seems plausible albeit speculative.

An explanation of the seismic activity in the New Madrid region is far more difficult to frame than an explanation of the activity along the San Andreas fault. For example, the California fault has a prominent surface scar with measurable offsets and well-mapped main and auxiliary traces. The opposite is true at New Madrid: the faults are deeply buried under the river sediments and the even thicker underlying marine sediments deposited on the floor of an ancient sea. No permanent surface fault traces, such as the waterfalls or rapids produced by the hard shock of February, 1812, are now found anywhere in the Mississippi embayment; any that may once have existed have long ago been removed by erosion and the reworking of sediments.

The fundamental difficulty lies in explaining why the Mississippi embayment has earthquakes at all. The San Andreas, after all, is a plate-boundary fault and has been recognized as such ever since the formulation of the theory of plate tectonics in the early 1960's. A plate is a rigid, strong section of the lithosphere: the outermost rock layer of the earth that includes the crust and the upper mantle. It behaves as a single body, and it moves slowly in response to forces generated ultimately by the slow convective release of the earth's internal heat.

In California this movement averages about 5.5 centimeters per year as the Pacific plate slides northwest along the San Andreas fault system, the boundary between the Pacific plate and the North American plate. Where the movement is impeded, as it is today in northern and southern California, the fault is locked and is therefore storing up strain energy that will ultimately and inevitably be released. Given the fact that the average displacement in a major earthquake is from six to eight meters, the recurrence time for a large earthquake along the San Andreas fault is roughly 110 to 145 years, unless smaller and more frequent earthquakes dissipate the energy now stored in the fault.

The New Madrid seismic zone, however, is not a plate boundary, and no such obvious calculation of recurrence



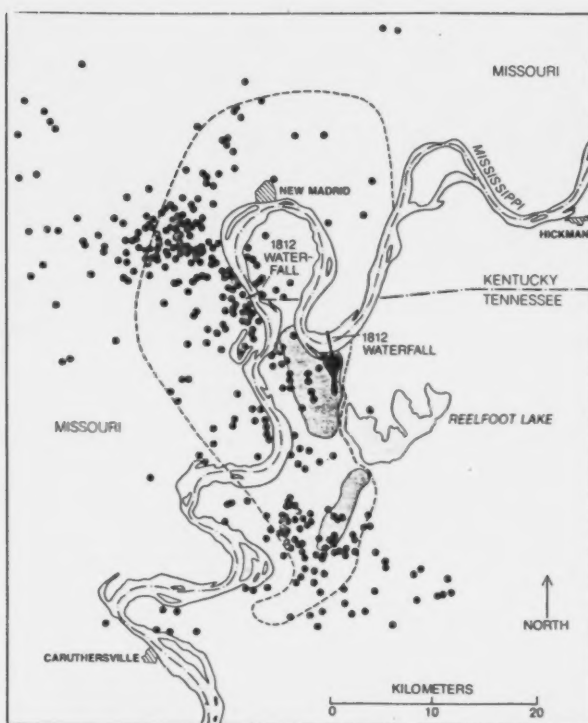
LANDSAT IMAGE of the area surrounding the confluence of the Mississippi and the Ohio (top) shows the narrowness of Thebes Gap. The map of the same area (bottom) locates faults on two upland blocks (colored lines) traced by the Missouri Geological Survey and indicates two former courses of the Mississippi. The river's shift to Thebes Gap may be the result of flood erosion or stream piracy, but the presence of a fault suggests a tectonic involvement.

time can be made. Indeed, the earthquakes in the New Madrid Zone are of the rare kind known as midplate quakes, a class of disturbances that is of little significance on a worldwide scale. There is still no explanation of midplate earthquakes in plate-tectonic theory. The fact remains that the New Madrid earthquakes of 1811-12 are prominent examples of these generally rare events.

Data from the seismograph networks in the Mississippi embayment yield an informative picture of the continuing New Madrid activity. The seismometers have made possible the precise location of quake epicenters and hypocenters. (An epicenter is the surface projection of the hypocenter, or deep focus, of an earthquake.) Accurate timing is all-important to these determinations; an error of .1 to .2 second in the recorded time of arrival of a seismic wave can shift the calculated location of a hypocenter by several kilometers. As a result of the increased sensitivity of the newer instrumentation what formerly seemed a fairly random scattering of epicenters has now proved to be a much tighter group-

ing and one that exhibits several distinct linear trends. The epicenters of earthquakes of magnitude 1 or greater can be plotted with an uncertainty of one kilometer or less in latitude and longitude. The uncertainty with respect to the depth of the hypocenters, however, remains a matter of several kilometers.

A word about magnitude scales will be useful here. The first such scale was devised in 1935 by Charles F. Richter of the California Institute of Technology. Since earthquakes vary greatly in magnitude, he found a logarithmic scale convenient. Magnitude is therefore proportional to the logarithm (to the base 10) of the amplitude of a recorded seismic wave. An increase of one unit on the scale represents an increase in wave amplitude by a factor of 10, which in turn represents an increase in radiated seismic energy by a factor of about 32. Large earthquakes, say of magnitude 8 or larger, are thus many millions of times more energetic than an event of magnitude 1. For example, the New Madrid hard shock (magnitude 8.7) released in its seismic waves alone (not



RIVER TERRAIN in the New Madrid seismic zone includes a subtle feature known as the Lake County uplift. The broken line (color) outlines the entire uplift feature, mapped by David P. Russ of the U.S. Geological Survey. Gray areas above and below Reelfoot Lake are regions of higher uplift; the darkest zone adjacent to a bar (color) is the region of maximum uplift. It once stood more than 10 meters above the level bottomland. The colored bar and a second one downstream and to the west designate places where the earthquake of February, 1812, so disrupted the riverbed that waterfalls were formed. Reelfoot Lake was also enlarged as a result of the earthquakes in 1811-12. The uplift may have deflected the Mississippi westward near Hickman, Ky. Dots indicate some of the earthquakes recorded in the area since 1974.

including either the heat or the mechanical energy released) energy greater than the energy that would be released by the explosion of 150 million tons of TNT.

Today most of the New Madrid events are microquakes. In the period between mid-1974, when the modern seismograph network was established, and mid-1981 an average of more than 150 events per year with a magnitude greater than 1 have been recorded. Of this total of more than 1,000 quakes the local residents have reported feeling fewer than 50. This is about seven per year, or less than 5 percent of the total. Since the large earthquakes of 1811-12 only two events estimated at magnitude 6 or greater have been reported; the first was in 1843 and the second in 1895. There was no seismograph installation

in the region until one was set up in St. Louis in 1909. Since then no quakes capable of doing more than minor damage have been recorded. The most recent earthquake, an event of magnitude 5, occurred near Marked Tree, Ark., on March 25, 1976. It was felt in seven states.

Was the 1811-12 series of severe earthquakes a unique event? Recent work by Russ suggests otherwise. Digging a trench at one location in the uplift area of Lake County, he exposed two zones of deformed and faulted sediments. Russ attributes the condition of the sediments to the action of large earthquakes. Fragments of shell from the disturbed sediments have yielded carbon-14 dates of $2,000 \pm 250$ years before the present. Hence the disturbances, which long predate the 1811-12

events, suggest a possible repeat time for large earthquakes on the order of 600 to 800 years.

The pattern of microquake epicenters seems to reflect the orientation of three deeply buried faults in the New Madrid region. Two main trends are apparent. One fault, possibly segmented, appears to strike southeast from the town of New Madrid into the Lake County region of northwestern Tennessee. The other, a longer fault, runs for 100 kilometers southwest out of the Missouri "boot heel" into northeastern Arkansas, where it ends abruptly at the town of Marked Tree, 60 kilometers northwest of Memphis. A third and less developed fault trend extends northward from the first fault to the vicinity of Cairo, Ill. For all three segments the depth measurements of microquake hypocenters range from five to 20 kilometers below the surface, a depth that places the faults mainly in the granitic basement rock of the upper and middle continental crust.

The two main faults differ both in their strain-energy release and in their mode of faulting. The first fault, which I shall call the cross-embayment segment, generates four times as many microquakes as the second fault, or axial segment, but releases only a fourth of the seismic energy. The axial segment produces fewer events, but the shocks of larger magnitude tend to be concentrated along it. This contrast may be due to differences in the stress levels; the rock of the axial segment may be stronger and less fractured than the rock of the cross-embayment segment and therefore able to store more strain energy between releases.

Faults can also differ according to the displacement of one side with respect to the other. For example, a steeply dipping fault that exhibits only horizontal movement is termed a strike slip. If the opposite side moves to the right, the fault is said to have a dextral offset; if it moves to the left, it is said to have a sinistral offset. As another example, if the overriding block of an inclined fault plane moves upward, it is said to be a thrust fault; if it slips downward, it is said to be a normal or gravity fault. These are more than mere classificatory distinctions; different types of faulting require a different orientation of the prevailing stress field. Strike-slip and thrust faulting require a horizontal maximum compressive stress; gravity faulting requires a vertical maximum compressive stress and a horizontal minimum compressive stress or even a tensional stress.

By studying the seismic wave patterns generated by New Madrid earthquakes Robert B. Herrmann of Saint Louis University has determined the dominant faulting types of the main fault segments. He finds that on the axial segment (and possibly on the Cairo segment) dextral strike slip predominates. The results for the cross-embayment

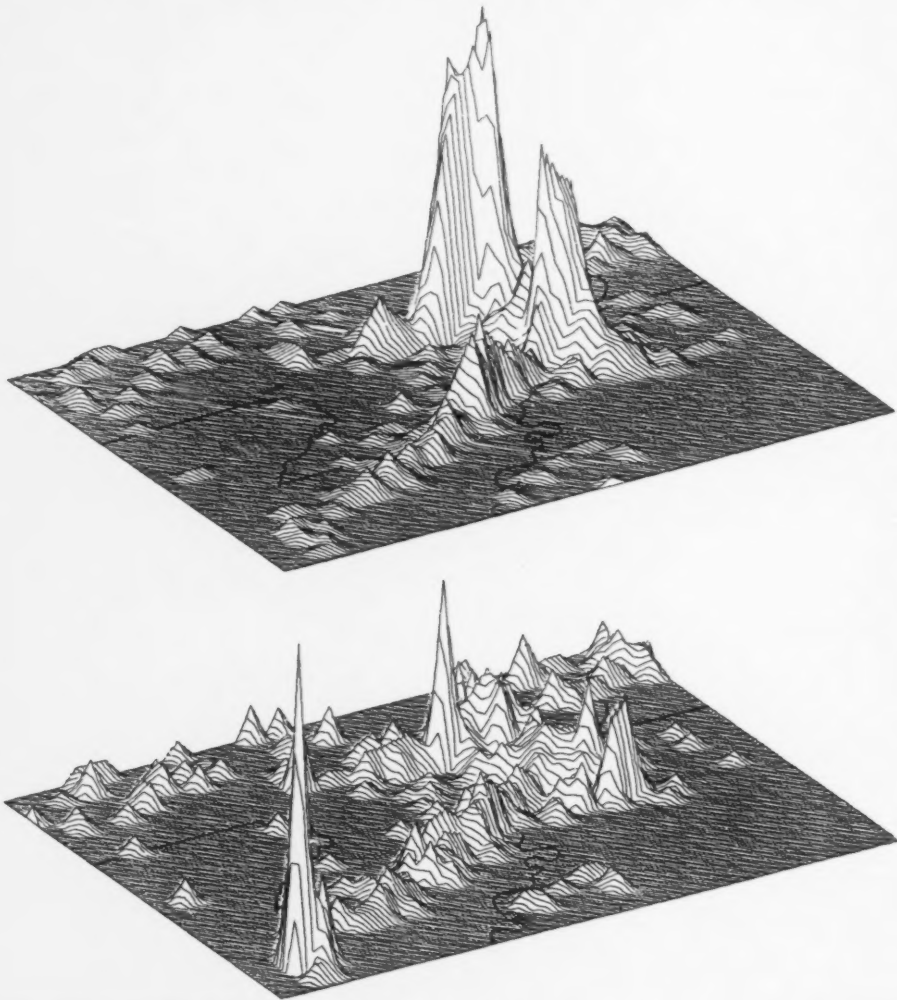
seignient are less clear but thrust faulting appears to be indicated. The presence of faults of these types is consistent both with the observed uplift in Lake County and with a single overall regional stress field: a maximum horizontal compressive stress with an east-west orientation. This agrees with the extensive North American stress measurements com-

piled by Mark and Mary Lou Zoback of the Geological Survey; these too indicate an east-west compressive stress field for much of the mid-continent.

The hypothesis is that the compressive stress is transmitted to the plate interior by interactions at the plate boundaries, or possibly by interaction of the rigid lithosphere with the more

ductile part of the immediately underlying mantle. In either case the source of the stresses that generate the New Madrid earthquakes is plate motion and the source of plate motion is the heat of the earth's interior.

To know that plate motion is the source of the earthquake-generating stress regime in the New Madrid region



COMPUTER-GENERATED PLOTS measure the earthquake activity of the New Madrid seismic zone. In the upper plot the height of a peak is proportional to the number of earthquakes recorded since July, 1974. The highest peak represents 19 quakes within a zone two square kilometers in extent. This and the next-highest peak overlie

fault-segment intersections. In the lower plot peak height represents the cumulative seismic energy released. The vertical scale is exponential; if it were linear, the tallest peak would be more than a million times higher than the low ones. The peak in the lower-left corner represents a 1974 magnitude 5.0 earthquake and its 4.5 aftershock.

is to see only half of the picture. One must also account for the mid-continental faults themselves. Furthermore one must ask why this particular combination of faults and stresses is seismically active when other mid-continental areas subjected to the same regional stresses show little if any such activity. A beginning can be made by summarizing what has been learned about the structure of the earth's crust in the Mississippi embayment.

A wealth of new information concerning the embayment has come from research programs conducted by the Geological Survey and by the New Madrid Seismotectonic Study Group, which is supported by the Nuclear Regulatory Commission. The findings indicate that the crust underlying the embayment is weakened by an ancient rift. The faults associated with the rift may have been inactive for millions of years, but they have now been remobilized. The remobilization is attributed to the present mid-continental regime of east-west compressive stress. Both the stress and the displacements it has induced,

however, appear to be quite different from the stress responsible for the initial rifting.

Continental cratons are among the least seismic regions of the earth. The crustal rock underlying the Mississippi embayment, however, appears to represent a "reentrant" into the North American craton; it is not a part of the cratonic block but is rock that is more characteristic of the coastal plain to the south. Such indentations are characteristic of a "failed arm" of three-armed rift systems that are associated with "hot spots" or "plumes" in the earth's mantle. Kevin C. Burke and John F. Dewey of the State University of New York at Albany suggest that such a hot spot underlay the North American craton in this rifted area some 300 million years ago; other estimates suggest that the hot spot was much more ancient, well back in Precambrian times of more than a billion years ago. A hot spot is not the only mechanism that could have produced the crustal rifting, but it is one that serves as a useful working model.

The designation "failed arm" indicates that this particular rift segment did not develop into an active, divergent plate boundary. (The other two arms may or may not have developed into such a boundary.) The failed arm would nonetheless exhibit all or most of the characteristics of an active continental rift: stretched and faulted crust, intrusions of dense magma from the mantle, positive gravity anomalies and an initial doming, followed by subsidence, as the mantle magma intruding into the lower crust cools and contracts. Rivers will often occupy such a subsided rift, and over the thinned and faulted crust thick layers of sediment will accumulate.

How well does the Mississippi embayment match this model of a failed-arm rift? Recent geophysical investigations that probe subsurface geological structures far beyond the reach of the deepest drill holes support such an interpretation. Gravity measurements have detected plutons (intrusions of dense mantle rock that increase the local gravity field) in the crustal rock of the embayment. The study of seismic waves reflected off subsurface structural discontinuities points to a thin crust within the embayment, underlain by a pillow of anomalous mantle rock.

Still further support for the rift model has come from field work in 1977-78, when Tom Hildenbrand and his colleagues of the Geological Survey carried out an extensive aerial magnetic field study of the region. Like gravity, the magnetic field of the earth is affected by the character of the subsurface rock. For example, the high iron content of igneous rock, such as mantle magma, gives rise to strong magnetic readings and the low iron content of sedimentary rocks gives rise to weak readings.

Hildenbrand's survey made use of a data-enhancement technique that not only revealed igneous intrusions but also located the boundaries of quite small intrusive bodies. A "contour" map incorporating these enhanced data shows a zone of reduced magnetism that runs through the New Madrid region in a northeast-southwest direction and separates flanking areas that have numerous igneous intrusions and are therefore higher in magnetic intensity. The low-intensity zone, roughly 75 kilometers wide, extends from south of Memphis northward to near the apex of the Mississippi embayment. Hildenbrand attributes the reduced magnetic intensity within the zone to a two-kilometer subsidence of basement rock as the failed-arm rift cooled and was loaded with sediments. The axial trend of New Madrid seismic events parallels the ancient rift and is centered between its flanks.

The Geological Survey's magnetic-intensity data have convinced many geologists, including me, of the reality of a subsurface rift in the Mississippi embayment. Hildenbrand's findings have



NORTH AMERICAN CRATON is the area inside the heavy colored line. It is the oldest, strongest and most rigid crustal rock of the continent. Most earthquake activity is confined to its periphery (colored arrows). Earthquake activity along the boundary between the Pacific plate and the North American plate has been omitted from the map. The black arrows show the generalized horizontal stress fields present in the crust: compressive in the east and the mid-continent and tensional in the west. The craton includes both exposed basement rock (shield) and veneers of sedimentary rock (platform); they are outlined by broken black lines. The New Madrid seismic zone overlies not the craton proper but a deeply rifted "reentrant" of coastal-plain rock from the south into the craton. The data were compiled by Steven Wesnousky and Christopher Scholz of the Lamont-Doherty Geological Observatory of Columbia University.

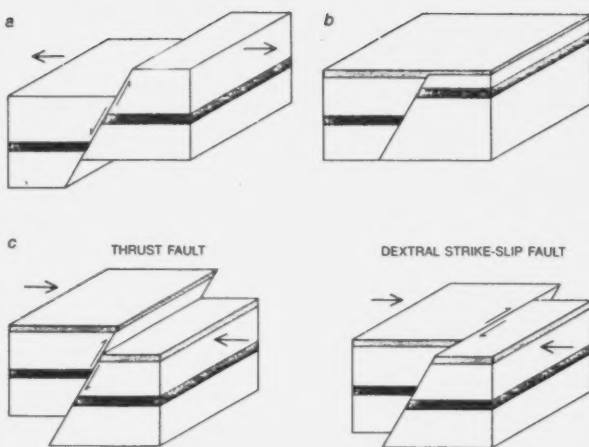
created a situation somewhat analogous to the acceptance of the reality of sea-floor spreading when in 1966 measurements revealed the nearly perfect symmetry of one particular magnetic-intensity profile on each side of the East Pacific rise. New concepts often need the support of a particularly clear piece of evidence in order to turn skeptics into believers.

Evidently at the time the rift was formed the North American craton was subjected to horizontal tensional stress. In today's regime of compressional east-west stress the gravitational faults associated with the initial rifting have been reactivated as faults of the thrust and strike-slip class. Robert M. Hamilton and Mark Zoback of the Geological Survey have recently applied a new technique of seismic analysis to identify for the first time the highly deformed fault zone that generates the axial-trend earthquakes in the New Madrid region. Two other Geological Survey workers, Ernest Glick and Anthony J. Crone, have shown that one fault on the south-east flank of the rift zone has been uplifted 80 meters since the time of the two-kilometer subsidence identified by Hildenbrand.

If one could forecast the rate of recurrence of major earthquakes in the New Madrid region, it would be possible to estimate its seismic vulnerability with fair precision. In the region of the San Andreas fault it is possible to make direct fault-slip measurements, but since this cannot be done in the Mississippi embayment, an alternative method is necessary. It stems from the empirical observation that for a given seismic region there is a linear relation between the magnitude of an earthquake and the logarithm of the cumulative number of earthquakes equal to or less than that magnitude.

This is simply a quantitative expression of the fact that small earthquakes are much more numerous than large ones. The slope of the best-fitted line on a graph plotting cumulative earthquake frequency against earthquake magnitude (known to seismologists as the b value) is commonly close to unity, so that there is a tenfold increase in the number of quakes for each unit decrease in magnitude. Once the b value and the proportionality constant of the equation are specified the average recurrence interval can be calculated for earthquakes of any given magnitude.

Working with a catalogue of historical New Madrid earthquake data compiled by Otto W. Nuttli of Saint Louis University and with the record of events detected since 1974, I have used the equation to estimate various New Madrid recurrence times. The range of elapsed times is enormous. Whereas, as I have noted, an earthquake of magnitude 1 can be expected almost every other



FAULT REACTIVATION is shown schematically. A gravity fault (a) forms when the horizontal component of the regional stress field (arrows) is tensional; one block sinks with respect to the other. Erosion and sedimentation (b) obliterate the surface evidence of the fault. The fault can be reactivated when compressive stress is applied (c). If the overriding block rises, the reactivated fault is of the thrust type, seen at the left. If one block moves horizontally with respect to the other, the fault is of the strike-slip type (motion to the right is dextral and motion to the left is sinistral). Oblique faulting, a combination of the two, is also possible. The gravity faults of the New Madrid seismic-zone rift exhibit both thrust and strike-slip reactivation.

day, an earthquake capable of major structural damage (about magnitude 6) can be expected only every 40 to 80 years. A repeat of an event greater than magnitude 8, such as those of 1811-12, is unlikely more often than at intervals of from 600 to 1,800 years. Obviously the larger the selected magnitude is, the greater the statistical uncertainties are. This results in estimates that have little practical value in the evaluation of risk. Nevertheless, even the empirical estimates are consistent with the results Russ obtained from the disturbed sediments in Lake County.

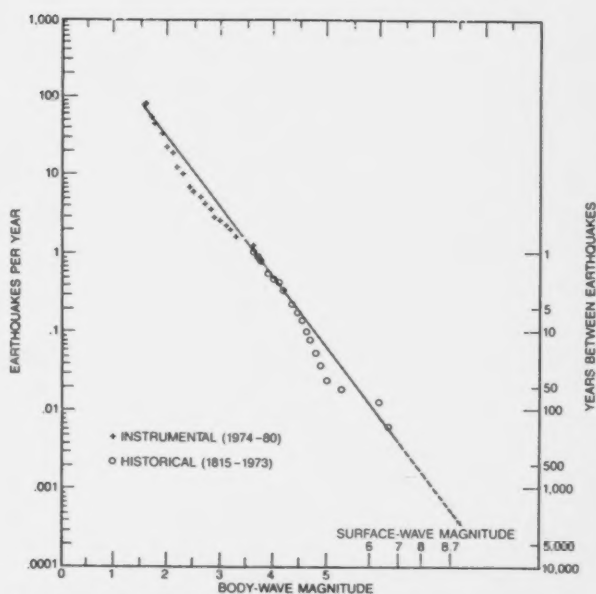
Even if the frequency of large New Madrid earthquakes cannot be estimated with anything resembling precision, it is still possible to make fairly good estimates of the extent of the damage that would result if such an earthquake occurred. For example, let us assume a recurrence of the 1812 hard shock. The most vulnerable large population center in the New Madrid area is Memphis. The city does not enforce any special seismic provisions in its building code. Moreover, the location of the city's buildings on the unconsolidated sediments of the Mississippi valley makes them far more susceptible to earthquake damage than structures with bedrock foundations would be.

In 1974 Clarke Mann and Warner Howe, consulting engineers in Memphis, joined Frederic H. Kellogg of Memphis State University in an evalua-

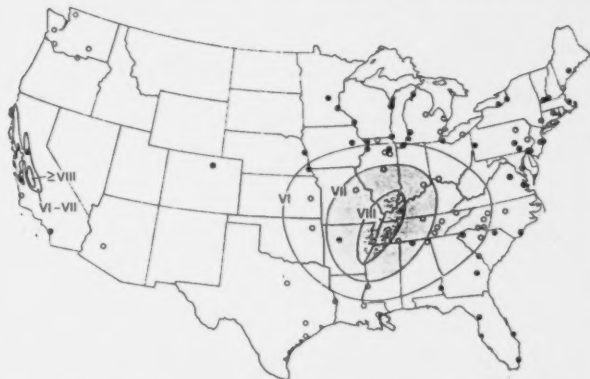
tion of seismic hazards in the city on behalf of the Department of Housing and Urban Development. If a maximum New Madrid earthquake were to occur in the daylight hours in the year 2000, they estimated, more than 3,000 people would be killed and the damage to buildings (measured in 1970 dollars) would exceed \$1.3 billion.

The damage from such an earthquake would not, of course, be limited to Memphis. In a similar estimate that Nuttli prepared on behalf of the Federal Emergency Management Agency he predicted structural damage to buildings and to "lifelines" such as bridges, utilities and pipelines not only in Tennessee but also in parts of six other states: Arkansas, Illinois, Indiana, Kentucky, Mississippi and Missouri. This is a much larger area of damage than can be expected for an earthquake of similar magnitude in California because the crustal rock of the western U.S. attenuates seismic waves over much shorter distances than the crustal rock of the central U.S. does. The agency's preliminary damage estimate for this extensive region, considering only damage to buildings, came to \$13 to \$14 billion (measured in 1980 dollars).

Even if the private citizen chooses, in view of the centuries between major earthquakes in the estimates, to ignore the current risk presented by the New Madrid seismic zone, the designers and regulators of large and critical facilities



FORECASTING EARTHQUAKES in a particular seismic region is possible because when the cumulative number of earthquakes per year is plotted logarithmically against earthquake magnitudes, the plot approximates a straight line. The process is applied to New Madrid data in this graph. The graph has a double magnitude scale: surface-wave magnitudes (color) for large events and body-wave magnitudes for smaller ones. The plot indicates that an event greater than magnitude 8, such as those of 1811-12, is likely only once every 600 to 1,800 years.



AREAS OF DAMAGE from a recurrence of an earthquake of magnitude 8.6 in the New Madrid seismic zone, as estimated by Otto W. Nuttli of Saint Louis University, are compared here with those of the San Francisco earthquake of 1906. Both quakes are roughly of the same magnitude; the areas of damage differ greatly because the crustal rock in the west attenuates seismic shock over much shorter distances than the crustal rock of the central U.S. does. Colored areas are where buildings were structurally damaged in the San Francisco area and where similar damage can be expected from a New Madrid recurrence. The gray area in California is where the architectural damage ranged from minor to significant. The inner gray area surrounding the central New Madrid damage zone is where significant architectural damage could be expected; the outer gray area is where architectural damage would be minor. Colored dots locate operating nuclear power plants; colored circles, plants planned or under construction.

cannot do so. In particular the siting and construction of nuclear power plants are determined in large part on the basis of the estimated earthquake hazard. For example, every nuclear plant built or under construction in the U.S. is designed to withstand two hypothetical earthquakes.

The first of the two is known as an "operating basis" earthquake (OBE), one that would not impair the ability of the structure to continue to operate safely. The second is known as a "safe shutdown" earthquake (SSE), one that would require the shutdown of the plant but would leave functional all systems required for public safety. The hypothetical SSE tremor, normally about twice as powerful as the OBE tremor, represents the maximum potential ground motion estimated for the area concerned and generally has a very low probability of occurrence. In much of the central U.S. assuming a quake equivalent to the New Madrid hard shock of 1812 calls for vibration estimates so large that to satisfy SSE design requirements becomes prohibitively expensive. This is the reason no nuclear plants have been built within the Mississippi embayment and why the design criteria of nuclear facilities nearby include the ability to withstand an imagined maximum New Madrid quake in the section of the rift closest to the plant.

The nuclear power industry faces a dilemma in dealing with earthquake hazards. On the one hand overconservatism in plant design can add tens of millions of dollars to construction costs. On the other hand the Nuclear Regulatory Commission cannot and does not ignore the possibility that the New Madrid seismic zone extends hundreds of kilometers northeast along the Wabash River fault system into Indiana. At the same time until it is better understood why the New Madrid region is active whereas similar continental rifts remain seismically quiescent no one can be sure that what are now inactive zones may not someday generate large earthquakes. For example, dozens of old, inactive faults and rifts are known to exist in the eastern U.S. Should all nuclear facilities in this region therefore be designed to withstand the high energy inputs from possible large earthquakes?

To answer these questions and many others will require a precision of geophysical and geological knowledge that does not now exist. Continuing study of the vast and complex natural laboratory we call the New Madrid seismic zone should nonetheless lead to a deeper understanding of the geological environment in general. The goal is not only to satisfy man's natural curiosity about why things are the way they are; it is also to be better prepared when the next great New Madrid earthquake inevitably comes.

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GRANTS AND SPONSORED RESEARCH - A.C. Johnston
(Principal or Co-Principal Investigator)

1. U.S. Nuclear Regulatory Commission

"Memphis Area Regional Seismic Network"

Sep, 1978 - Nov, 1979	:	\$65,544	awarded
Dec, 1979 - Nov, 1980	:	\$65,772	awarded
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Dec, 1982 - Nov, 1983	:	\$75,000	awarded
Dec, 1983 - Nov, 1984	:	\$97,000	awarded

2. U.S. Nuclear Regulatory Commission

"Southern Appalachian Seismic Network"

Sep, 1979 - Nov, 1980	:	\$69,355	awarded
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3. Tennessee Valley Authority

"TVA/TEIC Cooperative Seismic Research Project"

Aug, 1982 - Aug, 1983	:	\$7,800	awarded
Aug, 1983 - Aug, 1984	:	\$7,800	awarded

4. U.S. Geological Survey

"Earthquake Prediction from Swarm Activity: A Test of Proposed Earthquake Precursors"

Jan, 1983 - Dec, 1984	:	\$15,000	awarded
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5. U.S. Nuclear Regulatory Commission

"Strong Ground Motion/Digital Recording Instrumentation"

Dec, 1982 - Dec, 1983	:	\$39,400	awarded
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6. National Science Foundation

"Time Series Analysis of a 20,000-Earthquake Data Set from the Central U.S."

Oct, 1983 - Mar, 1985	:	\$30,700	awarded
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7. U.S. Geological Survey

"Historical Seismicity of the Southern Appalachian Seismic Zone" (with D.J. Reinbold)

Feb, 1984 - Feb, 1985	:	\$38,109	awarded
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SUBMITTED (Pending):

U.S. Geological Survey

"Seismic Velocities and Crustal Structure of the Southern Appalachians of Tennessee and North Carolina" (with D. Reinbold)

Requested Start Date:	1 October 1984
Requested Amount :	\$99,500

U.S. Geological Survey

"Continued Investigations of the Seismotectonics of the 1982-1983 Arkansas Earthquake Swarm"

Requested Start Date:	1 January 1985
Requested Amount :	\$74,590

Mr. GORE. Thank you very much, Dr. Johnston.

We'll hold off on our questions until the panel has been completed.

The last member of this panel is Dr. Joanne Nigg, acting director of the Office of Hazards Studies at Arizona State University. We are delighted to have you here, Dr. Nigg, and please proceed with your statement.

Dr. NIGG. Thank you.

In my presentation this morning, I would like to summarize for you the research that is being conducted by social and policy scientists on earthquake threat in the Eastern United States, and the implications of those research findings for mitigation and preparedness planning. Most of this—

Mr. GORE. If you could hold off one moment, I would like to welcome some visitors to the subcommittee from NATO, the NATO Science Committee. We are delighted to have you visiting, and I would like to invite you to take these seats in front here, if you would care to. Please do. And then you can—you can feel free to stand up and leave any time that your schedule calls for you to do so. We will make you honorary members of our Science and Technology Committee for this earthquake hearing.

Thank you, Dr. Nigg. Please let me explain to—if you will hold off for just a second, let me explain to our colleagues from NATO that this is a hearing on earthquake research into earthquakes in the Eastern United States. Much of the attention and focus on earthquakes in our country has been on earthquakes in California because of the well-known San Andreas Fault there and the high probability of a damaging event there in the future.

But research has shown very clearly that the largest earthquakes in the United States have occurred in the Eastern United States, specifically along an area called the New Madrid Fault and near the Tennessee-Missouri-Arkansas border, near the Mississippi River there. In 1811 and 1812, there were 3 earthquakes over 8.5 on the Richter scale there, and some 10 or 12 others that were very large earthquakes—Reelfoot Lake was created in Tennessee, church bells were rung thousands of miles away. And pressure has built up, and there is some possibility of another event in the range of 7.6 on the Richter scale, although a larger event is probably several hundred years off, although you can't say with certainty because it is more difficult to measure these zones in the Eastern United States.

We've asked for this hearing here, and invited scientific experts from around the country and experts in the ways that States and cities can prepare for the damage that might attend an earthquake, and we are reviewing what has been done in the area of research and in the area of preparation in hopes that this hearing will identify ways in which we can improve these efforts. We usually have our witnesses in panels, and we are about to complete our first panel.

I want to recognize the chairman of the full committee, Congressman Fuqua, who is joining us as well. Do you care to make a statement, Don?

Mr. FUQUA. No; we just have some NATO Science Ministers, and they want to see how a committee hearing operates. We thank you for taking time to explain the purpose of the hearing.

Mr. GORE. Glad to do it.

Mr. FUQUA. And I think they have to be leaving right shortly, too.

Mr. GORE. That is fine.

We have two kinds of hearings, generally speaking. One is a legislative hearing which is focused on specific legislation. And the other kind of hearing we have frequently is called an oversight hearing. This is an oversight hearing. We are trying to find out what is going on and identify what may need to be done. Specific legislation is not pending in this hearing, but we are trying to learn. It's sort of a factfinding hearing, if you will.

Dr. Joanne Nigg is the acting director of the office of hazards studies at Arizona State University. She was just about to begin her statement, and we will invite you to proceed, Dr. Nigg.

Dr. NIGG. Thank you.

I am going to be summarizing the status of societal and policy research in the area of the Eastern United States.

Unfortunately, most of the research that I am going to be talking about this morning is still in progress because social scientists and policy scientists have just begun to investigate the potential impacts of destructive eastern earthquakes within the last 2 or 3 years.

I have organized my remarks this morning around three key societal response issues. The first is the level of earthquake hazard awareness in the Eastern United States. Obviously, before a person can respond to a situation, he or she must know that it exists, or that some threat exists. In areas of the world where seismic activity is high—for example, in California, Japan, and Italy—public knowledge of earthquake threat is often taken for granted. People who live in these areas, even for a short time, are likely to have personally experienced a small-magnitude earthquake, and may even have experienced a destructive-magnitude quake. This awareness of threat provides a basis from which preparedness planning and mitigation activities can be undertaken.

We must know, however, if easterners are even aware that an earthquake threat exists in their region. If they are aware, how real does the possibility of a quake within the near future seem to them. Without some awareness, no preparedness or mitigation at either the individual or the governmental level is likely to take place.

In the first study that addressed the issue of earthquake threat awareness in the Central United States, two researchers interviewed elected officials, engineers, planners, and building inspectors in the State of Missouri between 1980 and 1981. At that time, they found that almost 90 percent of their key actors believed that earthquake risk was serious for the State of Missouri, and over 85 percent were somewhat or very concerned that the occurrence of such an earthquake would result in major damage and life loss.

This concern for seismic safety, however, was not at that time translated into widespread preparedness or mitigation efforts by governmental agencies. One explanation for this discrepancy be-

tween a high level of concern about seismic threat and the low amount of mitigation activity was a general belief in the State of Missouri at that time that the public was unaware of the earthquake hazard and did not think it was a serious enough problem to be addressed.

Not only in Missouri was this region—reason given for not taking a more active stance toward seismic safety measures, but the lack of public concern—the perceived lack of public concern—about earthquake threat was frequently raised by emergency managers and elected officials in several Eastern States. Without a constituency to support them, few hazard reduction efforts took place.

But is the public really unaware of earthquake threat? In the first study of public perception of seismic hazard conducted outside of California, a colleague and I have interviewed over 2,100 residents in 6 Central States—Arkansas, Illinois, Indiana, Kentucky, Missouri and Tennessee—during the last 6 months. From our preliminary findings, the general public is definitely aware of the possibility that a large-magnitude earthquake could cause damage in communities in which they live at any time in the near future, and a substantial proportion of those citizens also feel that there is a—there is probably or definitely going to be a damaging earthquake in their communities before the year 2000.

In the Central States, we now have knowledge that seismic hazard awareness and concern exists among the general public, as well as among key actors at the local level. Against this backdrop, researchers are beginning to investigate the conditions under which seismic safety policies, both preparedness and mitigation, develop.

In the Northeastern and Southeastern United States, however, we still know almost nothing about the actual levels of awareness and concern, either among the general public or among key actors, elected and appointed officials.

The second issue I would like to address is that which affects societal response and involves the understanding and assessment of earthquake threat by populations at risk. There are, in general, four frameworks, four areas of information that help people interpret knowledge about threat and earthquakes, whether something can be done about it, what needs to be done about it. And those four factors include current disaster folklore and popular beliefs about historical seismic events. Second, the carryover effects of experience with other disaster agents—can experiences in tornadoes and floods be carried over into earthquake preparedness measures? Third, are regional cultural beliefs and ways of coping with threat which research has established exist, especially between the Central United States and the Southeast? And fourth, are there ethnic group differences that affect changes in perception and levels of concern over natural hazards, threats, and disasters?

It is important to understand these variations because they provide a basis from which one component of a major public education program could be developed, the establishment of realistic expectations about earthquake threat—for example, by reviewing the popular lore about the consequences of the 1811 and 1812 New Madrid earthquakes—for example, the Mississippi River flowing backwards, whole communities collapsing, rivers changing their course

of flow, et cetera. Residents could be reminded of the region's seismic history, and a then and now comparison could be made. The important point here is to build on the familiar, correcting popular but perhaps erroneous perceptions. Little is currently known, however, about eastern citizens' understandings of earthquake causes and their consequences.

The third area of societal response research I would like to cover this morning concerns preparedness planning and mitigation issues.

I mentioned that a general awareness of earthquake threat is necessary but not sufficient for the development of a general concern about preparedness and hazard mitigation. The primary problem, it appears, is to get people to take protective actions. At bottom, this is an informational problem at both the personal and the organizational level. Despite the moderately high levels of awareness and concern we have found in the Central United States, we anticipate that the public's actual level of preparedness is low.

Preliminary impressions from our current research in the six-State area suggest that the major reason for this inactivity is due to a lack of knowledge about what can be done by citizens to protect themselves. Fatalism was very high with respect to whether activities in the preparedness mode would actually be effective or not.

Once public awareness begins to increase, however—and we have indications that it is definitely on the rise—and people start to ask what they can do to reduce the hazardousness of their immediate environment, they begin to engage in information-seeking activities. They turn to the media, to public service agencies, to local government officials, to emergency services and emergency management agencies. They also turn to local scientific organizations and universities to clarify the nature of the threat and to get suggestions about what to do to prepare for it.

The effect of this information-seeking activity is frequently to overwhelm these institutions with requests for written materials or speakers. For all of these organizations, the dissemination of earthquake preparedness information is a very small part of their overall functioning. In many cases, agencies refer information seekers to other agencies that they assume have more information, but this is an unfounded assumption. When agencies do have information available, it is frequently of a very general or superficial nature, or it originated in California and may not be appropriately transferred to the East.

What resources do currently exist to educate the public about protective measures? Where are they located? Where do people naturally turn for scientific information in their communities or for emergency response and preparedness information? Are these organizations that are turned to adequately staffed and funded? Are there personnel well trained? Clearly, more research needs to be done on the process of information dissemination and how to motivate people to use that information to enhance their own security.

The general low level of citizen preparedness in the Central United States, coupled with the surprising highly awareness and

concern about earthquake threat, has important implications for State and local governments. My colleague and I have found a strong citizen expectation that it is important for Government to take steps to lessen the effects of large-magnitude earthquakes. This raises the question: What are local and State governments doing to prepare for and mitigate the effects of damaging eastern earthquakes?

In the Central States, we have found an increase since 1981, the first study of its kind, in planning activities and attention to earthquake concerns by key actors. However, few policy changes with respect to building codes, construction practices, land use and inter-jurisdictional response planning formulation have taken place. Our research is currently trying to identify the factors that impede or facilitate the development of earthquake mitigation policies, particularly since we now know that citizens are definitely looking to Government for direction in this area.

Outside the Central States, again, little research has been done on this question. Two recent efforts have been made to monitor the progress of a consortium of citizens, scientists and engineers in Charleston, SC, to see whether they will be affected in motivating the formulation and adoption of governmental preparedness and mitigation actions in that State.

Obviously, major concerns of most of the key actors we have talked to and in the earlier study pertain to the economic consequences of policy changes. What financial resources are available for seismic safety efforts? Will changes in land use policies or construction practices have negative effects on communities' growth patterns? What kind of losses, in human as well as economic terms, can be anticipated? What are the most cost-effective steps governments can now take and what priorities should be attached to needed policy changes? What incentives exist or could exist for both the private sector and local governments to encourage the adoption of mitigation practices?

These are only a few of the research questions that still need to be addressed in order for us to begin to understand the dynamics which affect seismic safety policy development in the Eastern United States.

Thank you.

[The prepared statement of Dr. Nigg follows:]

STATEMENT OF DR. JOANNE M. NIGG, ASSISTANT PROFESSOR IN THE CENTER FOR PUBLIC AFFAIRS AND ACTING DIRECTOR OF THE OFFICE OF HAZARDS STUDIES AT ARIZONA STATE UNIVERSITY. MAY 23, 1984.

In my presentation this morning, I will be summarizing the research conducted by social and policy scientists on earthquake threat in the Eastern United States, especially that research which addresses earthquake hazard mitigation and preparedness planning. Most of this research, however, is still in progress because social scientists only began to investigate the potential impacts of destructive eastern earthquakes in the last four years or so.

I have organized my remarks around three key societal response issues:

1. Hazard Awareness
2. Understanding and Assessing Earthquake Threat
3. Preparedness Planning and Hazard Mitigation

EARTHQUAKE HAZARD AWARENESS

Obviously, before a person can respond to a situation, he or she must know that it exists. In areas of the world where seismic activity is high (e.g., California, Japan, Italy, Guatemala), the public's acknowledgement that earthquake threat exists is often taken for granted by researchers and planners. People who live in these areas, even for a short time, are likely to have personally felt small magnitude quakes; and many may have experienced or heard about the effects of locally destructive quakes. Research findings indicate that a substantial proportion of residents in these seismically active areas also believe that a damaging earthquake is likely within the near future (Turner, et al., 1980). This awareness of threat, then, can provide a basis from which preparedness planning and actions can be undertaken.

We must know, however, if Easterners are even aware that an earthquake threat exists in these regions. If they are aware, how real does the possibility

of a quake within the near future seem to them? Without some awareness, no preparedness--at either the individual or governmental level--will take place.

In the first study that addressed the issue of earthquake threat awareness in the Central United States, Drabek and Mushkatel (1983) interviewed key actors (elected officials, engineers, planners, building inspectors, etc.) in the state of Missouri in 1980-1981. At that time, they found that a surprisingly large proportion of their key actors believed that earthquake risk was serious in the state of Missouri (88 percent) and were somewhat or very concerned that the occurrence of such an earthquake would result in major damage and/or life loss (85 percent).

This concern for seismic safety, however, was not translated into widespread preparedness or mitigation efforts by governmental agencies. One explanation for this discrepancy between a high level of concern about the seismic threat and the low amount of mitigation activities was a general belief among the key actors in Missouri that the public was unaware of the earthquake hazard and did not think it was a serious problem. Not only in Missouri was this reason given for not taking a more active stance toward seismic safety measures, but the lack of public concern about earthquake threat was frequently raised by emergency managers in several Eastern states. Without constituency support, few hazard reduction efforts took place.

But was the public really unaware of the earthquake threat? In the first study of public perception of seismic hazard conducted outside of California, Mushkatel and I have interviewed almost 2100 residents in six states--Arkansas, Illinois, Indiana, Kentucky, Missouri, and Tennessee--during the last six months. From our preliminary findings, the general public definitely is aware of the possibility that a large magnitude earthquake could cause damage in the communities in which they live at any time in the near

future. A substantial proportion of these citizens also feels that there probably or definitely will be a damaging earthquake in their community before the year 2000.

In the Central states, then, we have established that seismic hazard awareness and concern among the general public as well as among key actors exists. Against this backdrop, researchers have begun to investigate the conditions under which seismic safety policies, both preparedness and mitigation, are developed. In the northeastern and the southeastern United States, however, little is known about the actual levels of awareness of and concern about earthquake threat.

UNDERSTANDING AND ASSESSING EARTHQUAKE THREAT

Merely being aware that a destructive magnitude earthquake could occur in one's region of the country is not sufficient to motivate either individuals or communities to take preparedness or mitigation actions. Several factors mediate awareness and response, determining how the earthquake threat will be interpreted.

Frameworks of Knowledge about Earthquakes

Before people can interpret information and decide how they are going to react to it, that information must be categorized in some way to make it meaningful. Since earthquakes, even non-damaging ones, are uncommon events in the lives of Easterners, we must look at the frameworks within which this information may be interpreted in order to understand how it may be responded to.

Disaster Lore and Popular Beliefs

What awareness there is may be influenced by earthquake lore and folk beliefs. Without frequent seismic events which prompt the retelling of such lore and folk beliefs, popular knowledge about the causes of earthquakes and what happens when they occur may be meager in the Eastern United States. But

some lore must exist, especially with regard to the 1811 and 1812 New Madrid quakes and the 1886 Charleston quake.

It is important to recover these beliefs and tales of local earthquake lore because they can provide a basis from which one component of a public education program could be developed--the establishment of realistic expectations of earthquake threat. For example, by reviewing the popular lore about the consequences of the 1811-1812 New Madrid quakes--the Mississippi River flowing backwards, whole communities collapsing, rivers changing their course of flow--residents could be reminded of the region's seismic history and a "then-now" comparison could be made. The important point here is to build on the familiar, correcting the glaringly erroneous popular perceptions and extrapolating to the present from the valid recollections of past local events. Little is currently known, however, about Eastern citizens' understanding of earthquake causes and consequences.

Disaster Subcultures

More so than in the West, the three regions in the Eastern United States with high seismic risk are frequently threatened by other natural disasters. The New Madrid fault zone is almost entirely overlapped by one of the highest tornado death index areas in the country (Sims and Baumann, 1974), the South Carolina coast and the Boston-New York areas have been threatened by hurricanes, and the Mississippi River Valley frequently experiences severe flooding.

The recurrent, destructive nature of these hazards has led to the development of warning systems, mitigation measures, and emergency response planning. Normal social relationships are replaced during these periods of imminent danger with another set of expected behaviors and organizational responsibilities that last as long as does the disaster threat or its aftermath. These areas, then, have disaster subcultures that aid people in knowing what to expect and how to respond.

But are the adaptive responses associated with, for example, a tornado disaster subculture transferable to earthquake threat situations? It is possible that experience with tornado warning systems and taking precautionary actions to protect one's household during watches and warnings may have some carryover effects which sensitize people to the importance of earthquake forewarning and hazard mitigation programs. This is an area that needs additional research--which precautions will be adaptive and which may lead to increased risk? This is a particularly important area of needed research because of FEMA's emphasis on comprehensive emergency management, a planning technique which encourages an "all-hazards" approach.

Regional Differences

Research on disaster subcultures has also indicated that there are regional variations in communities' adaptive responses to threat, with the Central states having lower fatality rates from tornado events than do Southern states (Sims and Baumann, 1974). Since no substantial differences between regions were found in the number, duration or velocity of the tornados, when they hit, the types of residential structures, or the quality of the warning systems, researchers investigated how the populations of the two regions differed.

Two significant differences were found in the ways people interpreted and coped with threat of disaster. First, Central states residents expressed the belief that they were more in control of their own lives than did Southerners who were more likely to identify some force external to themselves (e.g., luck or God) as a causal agent in their lives. Second, Southerners were more likely to rely on their own senses to keep themselves informed about the impending disaster opposed to Central states residents who relied heavily on the media.

Whether local disaster subcultural procedures and behaviors can be adapted to cope with earthquake threat, then, may not be just a question of

how much overlap there is between the mitigation and preparedness needs associated with both types of disasters. Regional variation in interpreting and responding to any threatening situation will have to be taken into consideration.

Ethnic Subcultures

These indications of regional differences point to another feature of social life that affects the ways people understand and respond to threat--their ethnic or racial group identification.

In southern California, substantial differences in earthquake perception and responses were found among Anglos, Blacks, and Mexican-Americans in several areas--the amount of fear and concern they had about a future damaging quake; fatalistic attitudes about the importance of preparedness; use of the media for information on earthquake threat; degree of personal preparedness for a coming quake; and support for governmental expenditures for mitigation efforts (Turner, et al., 1980, especially Part Six). Even after taking socioeconomic factors into consideration, ethnic subcultural effects remained strong.

It seems reasonable to assume that ethnicity will also have substantial effects on perceptions of earthquake threat in the Eastern United States. What those effects will be, however, is largely unknown since there is likely to be a great deal of difference in orientations to earthquake threat between, for example, Black communities in highly urbanized southern California and those in rural South Carolina. Without more information about the frameworks that ethnic groups use to interpret earthquake threat, it will be difficult to develop public education programs that are meaningful to these special populations.

PREPAREDNESS PLANNING AND HAZARD MITIGATION

I have already mentioned that a general awareness of earthquake threat is necessary but not sufficient for the development of a general concern about preparedness and hazard mitigation. Our primary problem is to get people to

take protective actions. The problem of motivating people to take preparedness measures is, first of all, an informational problem at both the personal and organizational levels.

Despite the moderately high levels of awareness and concern we have found in the Central United States, we anticipate that the public's actual level of preparedness is low. Preliminary impressions from our current research in the six-state area suggest that a major reason for this inaction is due to a lack of knowledge about what can be done by citizens to protect themselves.

Once public awareness begins to increase and people start to ask what they can do to reduce the hazardousness of their immediate environment, they engage in information-seeking activities. They turn to the media, to public service agencies (e.g., fire and police departments), to emergency preparedness agencies and organizations (e.g., Civil Defense offices, State offices of emergency services, the Red Cross), to local government officials, and to scientific organizations and universities that are engaged in earthquake research for clarification of the threat and for suggestions about what to do to prepare themselves.

The effect of this information-seeking activity is frequently to overwhelm these agencies with requests for written materials or speakers. For all of these organizations, the dissemination of earthquake preparedness information is a very small part of their overall functioning. In many cases, agencies refer information seekers to other agencies that they assume have better information or more resources available; an assumption that is often unfounded. When agencies do have some information available, it is frequently of a very general nature that could be used in any type of emergency or its suggestions are superficial.

What resources do currently exist? Where are they located? Are they adequately staffed and funded? Clearly, more research needs to be done on the

process of information dissemination and how to motivate people to use that information to enhance their own security.

The general low level of citizen preparedness in the Central states, coupled with the surprisingly high awareness and concern about earthquake threat, has important implications for state and local governments. We found a strong citizen expectation that it was important for government to take steps to lessen the effects of large magnitude earthquakes. This raises the question, "What are local and state governments doing to prepare for and mitigate the effects of a damaging Eastern earthquake?" Outside of the Central states, very little systematic research has been done on this question. Lambright (1984) and Greene and Gori (1982) have monitored the progress of an ad-hoc consortium of citizens, scientists, and engineers, based in Charleston, South Carolina, to see how effective it is in motivating the formulation and adoption of governmental preparedness and mitigation actions. In the Central states, Mushkatel and I have found an increase since 1981 in planning activities and attention to earthquake concerns by key actors, but few policy changes with respect to building codes, construction practices, land use, and interjurisdictional response plan formulation. A major research effort should be undertaken to determine what factors impede the development of earthquake mitigation policies, particularly where citizens are looking to government for direction.

Obviously, major concerns of most key actors pertain to the economic consequences of policy changes. What financial resources are available for seismic safety efforts? Will changes in land use policies or construction practices have a negative effect on a community's growth? What kind of losses--in human as well as economic terms--can be anticipated? What are the most cost-effective steps governments can take now, and what priorities should be attached to needed policy change? What incentives exist or could exist--

for both the private sector and local governments--to encourage the adoption of mitigation practices? These are only a few of the questions that need to be addressed in order for us to begin to understand the dynamics which affect seismic safety policy in the Eastern United States.

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CURRICULUM VITAE

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1. ACADEMIC TRAINING

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|-------|------|---|
| B.A. | 1973 | California State University, Fresno. Sociology. |
| M.A. | 1975 | University of California at Los Angeles. Sociology. |
| Ph.D. | 1979 | University of California at Los Angeles. Sociology. |

Dissertation Title: The Emergence of Issues and Collectivities: Community Response to Earthquake Prediction and Its Consequences.

Doctoral Committee Chair: Ralph H. Turner

2. HONORS AND AWARDS

- | | |
|---------|---|
| 1975 | Regents Research Grant, UCLA |
| 1979 | UCLA Alumni Association Graduate Award, Social Science Division |
| 1980-81 | Research Assistant Award, Arizona State University |

3. TEACHING EXPERIENCE

- | | |
|--------------|--|
| 1984-Present | Assistant Professor, Center for Public Affairs, Arizona State University |
| 1979-1983 | Assistant Professor, Sociology, Arizona State University |
| 1977 | Teaching Fellow, Sociology, UCLA |
| 1975-76 | Teaching Associate, Sociology, UCLA |
| 1974-75 | Teaching Assistant, Sociology, UCLA |

4. TEACHING INTERESTS

Statistics
Methodology
Collective Behavior and Social Movements
Social Organization
Environmental Issues
Social Psychology
Survey Research

5. RESEARCH INTERESTS

Hazards Research
Formation of Public Opinion
Collective Altruism
Countermovements
Risk Assessment

6. ADMINISTRATIVE EXPERIENCE

Acting Director, Office of Hazards Studies. 1983-present.

Associate Director, University Survey Research Facility, 1982-1983.

Associate Director, Sociology Survey Research Laboratory, Arizona State University. 1979-1983.

Mr. GORE. Thank you very much.

Let me start off with a few questions, and then recognize my colleagues.

First of all, Dr. Nigg, summarizing your statement in my own mind, one of the things you're saying is that there seems to be a widespread acceptance among the general public that the earthquake hazards in the Eastern United States, particularly around the New Madrid Fault area, are quite serious, but that hasn't translated into action by governmental officials; is that—

Dr. NIGG. Yes.

Mr. GORE [continuing]. Essentially what you are saying?

Dr. NIGG. Yes.

Mr. GORE. How do you account for that discrepancy? Is it that it is the low probability event associated with large damages, and that the easiest response is just to push it away?

Dr. NIGG. Well, I think—I think that that's—there has—there is a tendency to not attend to the very low probability events because, given the maximum probable earthquake that is being talked about, the recurrence of the 1811 and 1812 quakes, to try to gear up to meet the construction needs, the seismic design resistance designs, all of the factors that need to be taken into consideration to protect populations, given that scenario, would be extremely expensive. The task is overwhelming, especially, I believe, at the local level, to begin to address that.

It may be more relevant, especially when we are looking at the development of policy, to begin with the more likely lower-magnitude yet still destructive quakes—

Mr. GORE. Yes.

Dr. NIGG [continuing]. To start to formulate the policy implications.

Mr. GORE. Yes, because clearly some preparations can make a big difference in how much damage occurs.

Dr. Johnston, in your Scientific American article, you described the damages that might be associated with the repetition of the 1811 quake. If that occurred in daylight hours in the year 2000, you wrote about the damages, and they are quite extensive and extremely grave.

How much of a difference would it make in those damages if an earthquake of 7.5 instead of 8.5 occurred? Would the damages be still in roughly the same dimensions?

Dr. JOHNSTON. Well, a 7.5 could be very destructive. It becomes more important where it is located. A magnitude 8½, the significant damage area is so large for many of the cities, it doesn't really matter—I am speaking of the New Madrid zone now—what portion of the zone it's located in. But you get down in the range of 6½ to 7, perhaps up to 7½, it does become important. For instance, it would be important whether it were in the northern part of the New Madrid zone or the southern part for the city of Memphis.

Those figures I used were from a 1974 study sponsored by HUD, Department of Health, Urban Development—

Mr. GORE. Housing and Urban Development.

Dr. JOHNSTON. Housing and Urban Development. And those are really—they were specific to Memphis, and they considered only permanent building damage. So those are the best figures we have.

Of course, there is the still pending FEMA study which may upgrade those figures somewhat, but those figures are a decade old.

Mr. GORE. We're going to discuss some aspects of the FEMA study a little bit later on in this hearing.

I would like to ask you, Dr. Johnston, and you, Dr. Nuttli, to help me get a clear view of exactly what the nature of the risk is. Let me state my understanding of it and let you modify it and correct it, OK?

It is difficult to measure the New Madrid Fault as we have measured the San Andreas Fault. But based on what we do know, it's fair to assume that the pressures have built up in the New Madrid zone to a level that would require an earthquake of about 7.6 on the Richter scale in order to release that pressure; is that correct?

Dr. NUTTLI. That is correct, yes, sir.

Mr. GORE. OK.

Now because of that assumption, you both believe that an earthquake of 8.5 on the Richter scale is extremely unlikely at the present time and unlikely for several hundred more years. Is that right or wrong?

Dr. JOHNSTON. That's essentially correct. You can't rule it out, but I would say it would be a very low probability.

Mr. GORE. OK. Now, do you agree with that?

Dr. NUTTLI. I agree with that, yes.

Mr. GORE. OK. Now, an earthquake of 7.5 or 7.6 could occur when?

Dr. NUTTLI. It could occur anytime, from now until some unknown time in the future.

Mr. GORE. All right. Now, is there a greater chance of it occurring the more time that passes? Is that essentially correct?

Dr. NUTTLI. As more time passes, the size of the earthquake will get larger because you will be relieving more energy that's been accumulated in that interval of time.

Mr. GORE. Are we better off to get it over with then?

Dr. NUTTLI. No; we might think of it as the fault being locked in place—

Mr. GORE. Yes, I understand.

Dr. NUTTLI [continuing]. And the forces, the geologic forces, are trying to make the two rock masses on either side of the fault slip some and cause the earthquake. So it's a fight between the geologic forces trying to overcome the friction, and the friction which is locking it together.

Mr. GORE. Yes.

Dr. NUTTLI. And there may be a weak spot where it breaks soon, which would be the magnitude 7.5 or 7.6, or it may be held together very tightly and it might take a long time until the forces become large enough to overcome that friction. We cannot predict the time of occurrence of its next bigger—

Dr. JOHNSTON. One point. Because of the exponential nature of the magnitude scale, this low-level activity we see now, and even activity up in the magnitude 6 or low 7 range, is insignificant compared to the energy of a magnitude 8 or 8.5 earthquake. So what we are seeing now is not—

Mr. GORE. It's not releasing much pressure.

Dr. JOHNSTON. That's right. It is not a safety valve.

Mr. GORE. Now, if I understand the Richter scale correctly, when you go from 6 to 7, it is not an arithmetic progression. When you go from 6 to 7, you have magnified the power by 10. Is that essentially right, or is it more than that?

Dr. JOHNSTON. The amplitude of the ground motion is a factor of 10. If you translate that into energy, it is actually a factor of about 30, energy released.

Mr. GORE. Thirty. So when you go from one number to the next highest number, you have magnified the energy release by a factor of 30?

Dr. JOHNSTON. That's right. And then if you go to the next unit, it is 30 times 30, it is multiplicative, so that a magnitude 8 is roughly—releases roughly 1,000 times more energy than a magnitude 6.

Mr. GORE. OK. But 30 times more energy than a magnitude of 7?

Dr. JOHNSTON. That's right.

Mr. GORE. OK. All right.

Now, what would you say the odds are of a quake in the 7.5 range between now and the year 2000?

Dr. NUTTLI. I wouldn't attempt to estimate the odds. It's very difficult because we don't know that—we cannot get down into the fault itself and make the kind of measurements we would need to make—

Mr. GORE. Yeah.

Dr. NUTTLI [continuing]. To be able to answer that question.

Mr. GORE. Dr. Johnston?

Dr. JOHNSTON. I would agree. I would think the odds would—I would say very low. But I wouldn't try to hone it down any more than that.

Mr. GORE. What would you say were the odds between now and the year 2050?

Dr. NUTTLI. Maybe getting larger, naturally. [Laughter.]

Mr. BROWN. Mr. Chairman?

Mr. GORE. Yes.

Mr. BROWN. Would you yield, please?

Mr. GORE. I would be glad to yield, surely.

Mr. BROWN. This is a question which has been frequently discussed in California where there is a bit of data.

Mr. GORE. I bet it has been.

Mr. BROWN. It is to the point where I think they have predicted in the major fault area in southern California a 50-percent chance, roughly, between now and 2000. And this is based upon fairly good data that gives you almost the ability to say, "Well, it's 2 percent per year building up."

Mr. GORE. Yeah.

Mr. BROWN. And it's that kind of data I presume we don't have for the Eastern United States; is that correct?

Dr. NUTTLI. That's correct, yes.

Dr. JOHNSTON. They have some very good geologic data where they can go back and look at data past large earthquakes in the San Andreas. That's the missing ingredient—

Mr. BROWN. That's the only point I would make.

Dr. JOHNSTON [continuing]. In the East.

Mr. GORE. Well, fine. Let me ask one more question, and then I want to recognize you.

Have you or Dr. Johnston—have you made an effort to identify people in Tennessee that have this so-called earthquake sickness, who have the ability to—to sense the precursors to earthquakes?

Mr. JOHNSTON. Well, we've had a number identify themselves to us—

Mr. GORE. Yes.

Dr. JOHNSTON [continuing]. At the Earthquake Information Center.

Mr. GORE. How many?

Dr. JOHNSTON. I would say—I have been there 5 years now, and probably 4 or 5, some of them quite persistent with predictions.

Mr. GORE. And are they accurate?

Dr. JOHNSTON. No, sir, they're not.

Mr. GORE. Dr. Nuttli, has this phenomenon proven to be accurate in some areas, hasn't it?

Dr. NUTTLI. Not that I'm aware of.

Mr. GORE. Never has been?

Dr. NUTTLI. No.

Mr. GORE. I had—all right. Well, let me come back to that.

I'm going to recognize my colleagues in order of their appearance. First, Congressman Brown.

Mr. BROWN. Well, just following up on that briefly, would you gentlemen and lady confirm whether to your knowledge or not there has been data collected indicating that there are animal sensitivities that might be considered precursor phenomena for earthquakes, at least in the near timeframe?

Dr. JOHNSTON. Yes, sir. I think the evidence is pretty much overwhelming that this is a true—this does actually happen, particularly just the repeated reports from China.

Our problem is we don't know what the animals are responding to. And whether it can be useful in a prediction sense, I think still has to be proven.

Mr. BROWN. Well, this is in the more esoteric range of earthquake research, but it is a potentially valid type of study, if nothing else, merely to understand what signals are being generated and responded to.

Dr. JOHNSTON. Yes, I would agree entirely, yes.

Mr. BROWN. Let me go to another area. I have been interested since following the original development of plate tectonics to understand something about the forces at work here and the knowledge now of it, and I was unable to understand just why we were getting earthquakes generated in the central parts of the United States until I looked at, Dr. Johnston, one of charts that you have included in your paper which seems to indicate there are subsets of the plates, that is that the plates are not monolithic, but they seem to be structured in some fashion and that there are boundaries, and it is along those boundaries that we get evidence of the earthquake; is that correct?

Dr. JOHNSTON. Yes, sir. This is not my own research. But I think there is very good evidence, most of it through the work of the U.S. Geological Survey and Nuclear Regulatory Commission, that the New Madrid area is what we call an old rift zone. And it may have

been a plate boundary in the far distant past, or it may have been a plate boundary that almost formed. But, in any case, it represents a very weak portion of the continental crust. So, given the same stresses over the region, that's the area where earthquakes would concentrate.

Mr. BROWN. You indicated that one of the areas of research which might be extremely useful was deep drilling in the continental crust, that would give you further information about some of this phenomenon that we don't understand.

We have been doing deep drilling in California in connection with another problem, that is, location and utilization of geothermal energy zones. I'm interested in knowing whether there is a possibility synergistic connection here since we tend to get geothermal energy released at areas—at boundaries between plates, or fractures in plates, whether or not it would not be reasonable to contemplate shared research here in which we could learn more about the geothermal energy resources, as well as plate structure, which would benefit us in several areas?

Dr. JOHNSTON. I think that would certainly be desirable. I think we would have a problem. The thermal gradient at the high temperatures are a good bit closer to the surface in the West, and so we have to go a good bit deeper in the East, which drives up the cost considerably.

Mr. BROWN. Well, what is the—we're drilling down to 3 and 4,000—no, 3 and 4 miles, 18,000 feet or better, in some parts of California. Are we talking about something substantially more than that?

Dr. JOHNSTON. I think it could be, yes. I think to combine it with deep drilling investigation of earthquake zones in the East, earthquakes are normally 5 to 15 kilometers deep, so 10 kilometers would be about 6 miles. That is very—those depths are very expensive to reach.

Mr. BROWN. Let me ask one additional question which bears more on the societal response and preparation for earthquakes, obviously a problem in the East where earthquakes occur infrequently. But what I've been trying to inculcate, and what others in this committee have been trying to inculcate, is the generic response to major hazards.

When you look at the problem from that standpoint and begin to contemplate the number of major disasters that we may be exposed to, which range all the way from nuclear war or astroidal collision, down to fires, floods, major accidents, nuclear plant explosions—in the West at least, volcanic explosions—it has seemed that the response to all of these is likely to have a large degree of commonality, and that an integrated hazard response program is—which the public becomes accustomed to the idea that we need to prepare for any form of major disaster might elicit the best response. Now, have any of you had experience or thought about that as an area of research which might be fruitful?

Dr. NIGG. I think that that's a very good point. And I—given the—the availability of resources and the need to manage those resources, emergency management and emergency resources, very carefully, given the multiplicity of hazards that affect—or potentially could effect any community, is an excellent idea.

One of the problems that recurs is whether the adaptive responses in one hazard, just looking at how the public respond, is transferable from one hazard to another. And—for example, there are certain protective actions that people take in tornado situations that may not be appropriate for an earthquake situation. I think that, for governmental planning purposes, that is probably an excellent idea. Certainly the principles of good emergency management planning are similar across all hazard events, and the same considerations for communication needs, coordinations needs, authority and hierarchical dmt certainly need to be there.

Mr. BROWN. Well, another aspect to this question of public awareness; you are able to get resources to prepare, to organize to prepare, only when there is a widespread public awareness. And it is easier to have the public aware of the totality of hazards that they're exposed to than it is for a very low frequency kind of event.

We have a similar problem in our response to the problem of chemical hazards, for example. The possibility of any one chemical be the cause of cancer is very, very low, but the cumulative effect of thousands of chemicals is likely to be rather serious. Yet, we deal with the chemical hazards on a one-by-one basis and, hence it's hard to get an adequate total public response or governmental response. Yet, the solution to that, the solution for any one chemical, is likely to be much the same as just forget it—reduce the hazard for one thing, reduce exposure.

Dr. NIGG. Uh-huh, yes.

Mr. BROWN. So far, we haven't seemed to have learned that lesson.

I have no further questions.

Mr. GORE. Congresswoman Schneider.

Mrs. SCHNEIDER. Thank you.

I am anxious to know what additional research needs to be done in order to put us in a position where we can better predict and also understand earthquakes?

Dr. NUTTLI. I think perhaps we should reverse the order.

Mrs. SCHNEIDER. OK.

Dr. NUTTLI. Let's—

Mrs. SCHNEIDER. Understand earthquakes.

Dr. NUTTLI. If we understand earthquakes, then we might be able to predict them.

Mrs. SCHNEIDER. Right.

Dr. NUTTLI. That is our principal objective right now, to understand the physical processes that go on before and during the occurrence of an earthquake.

Mrs. SCHNEIDER. But what more research does need to be done?

Dr. NUTTLI. We need continuing data of the type they have been gathering to either identify where earthquakes occur, or we also need some additional kinds of data. Congressman Brown was talking about these deep bore holes. If we could put strain instruments down in the bore holes, we could measure another property of the deformation of rock which might help us in predicting earthquakes. We don't have that capability at the present time.

Mrs. SCHNEIDER. Is it possible to identify exactly where, or as close to exactly as possible, where the fault line is?

Dr. NUTTLI. For the case of the New Madrid Fault zone, we believe that is so. Both the location of the earthquakes and the information given by geophysical studies by the U.S. Geological Survey, sending waves down as you do in looking for petroleum, indicate the—the fault location itself.

Mrs. SCHNEIDER. Well, since we can locate the fault and since there is concern that the longer time period between earthquakes lends to the severity in each quake, is it a reasonable question to wonder if it would be possible or wise to have a manmade igniting of an earthquake prior to its natural timing?

Dr. NUTTLI. This question has been discussed in the past very seriously. The problem is that the manmade earthquake, unless it were a very, very large earthquake, would not relieve much of the energy stored up on the fault. And let's suppose we take up—if we make 6—magnitude 6 earthquakes.

Mrs. SCHNEIDER. OK.

Dr. NUTTLI. And you want to relieve the energy equivalent to a magnitude of $7\frac{1}{2}$, you are talking about at least 100 earthquakes of a magnitude 6 to release the equivalent energy of 1 magnitude $7\frac{1}{2}$. I'm afraid the legal consequences will be so severe—

[Laughter.]

Dr. NUTTLI [continuing]. Nobody would ever really attempt it.

Mrs. SCHNEIDER. Not to mention the nerves of those people—

Dr. NUTTLI. Right.

Mrs. SCHNEIDER [continuing]. Living nearby.

Dr. NIGG, I'd like to touch a little bit on the role of the Federal Government in the whole analyses and prediction and the social impact network that evolves around earthquakes. And I am just wondering, it appears from your testimony that you have confidence in the Federal Government in being able to make decisions as to how people can better protect themselves against earthquake. You feel that the Federal Government needs to do more of?

Dr. NIGG. I think certainly that there is a role for the Federal Government in supporting the development of educational materials. It's a very expensive process, the publication, printing and dissemination of good quality materials that match the needs of the—the different populations that they address. And those are frequently resources that any individual State or county cannot afford. And I think that that is a very important role for the Federal Government to play, and I believe that they are beginning that process, with to earthquakes specifically, outside of California.

Mrs. SCHNEIDER. And the States and counties, of course, have the jurisdiction and responsibility to determine zoning and—

Dr. NIGG. Yes.

Mrs. SCHNEIDER [continuing]. And land use in fault area.

Of course, I can't help but think of the Federal Government's role in doing some siting of nuclear power plants in less than stable locations. And so I can't help but question your reliance on the Federal Government to make the appropriate decisions.

Dr. NIGG. Perhaps not make the decisions, but make the resources available for the development of educational materials.

Mrs. SCHNEIDER. That would be the primary area where you would see the role being played?

Dr. NIGG. Uh-huh.

Mrs. SCHNEIDER. OK. I don't think I have any further questions right now, Mr. Chairman.

Mr. GORE. Congressman McCandless. I'm sorry.

Mrs. SCHNEIDER. He's gone.

Mr. GORE. Oh, all right.

Mrs. SCHNEIDER. Mr. Bateman.

Mr. GORE. Mr. Bateman.

Mr. BATEMAN. Thank you, Mr. Chairman.

Can you tell me whether or not there's any clear basis for predictability or as to likelihood or less likelihood of an earthquake in a coastal plain area as opposed to a mountainous area, or can you describe the type of topography where you're more inclined to risk or less inclined to risk of a significant earthquake? Dr. Johnston, or either you or—

Dr. JOHNSTON. Well, it—just a general answer. It can vary greatly. Looked at globally, the Andes, for instance, are a very high active earthquake zone. The portions of the Rockies, the Appalachians, are not. The coastal plain, the Atlantic Coastal Plain, is of particular concern because of the 1886 Charleston earthquake, which no one knows why it happened there. And it is not an active earthquake zone such as we are used to dealing with. So there is a very large questionmark about Charleston.

And in general, earthquakes will happen where, for some reason or another—and the reasons can be quite varied—the crustal rock is weaker than the surrounding rock.

Mr. BATEMAN. And, predictably, that phenomena is, I take it, as likely to arise in level coastal plains environment as it would be in a mountainous environment?

Dr. JOHNSTON. Yes, it's certainly possible. The New Madrid zone, for instance, the very low level Mississippi embayment, Mississippi Valley, is the most active zone in the East. The overall question of reactivation of old features like old faults and rift zones, I think, is maybe the most critical question for the Eastern United States.

Mr. BATEMAN. Using the New Madrid earthquake phenomena in trying to understand the commentary in your testimony to the effect that, over time, there's going to be one and, the longer the time, the greater it's going to be, does Mother Earth have any capability through such phenomena as the New Madrid earthquake to adjusting its crust and curing its faults so that the problem thereafter goes away? Or is there this inevitability of you got to get one and, the longer you wait for it, the worse it's going to be?

Dr. NUTTLI. Well, eventually, knowing what we do, the fault must heal itself. We can see that happening in other parts of the world, a geologic record. But in a timeframe of human lives, we don't expect that to happen.

Dr. Russ of the U.S. Geological Survey has done some trenching along the New Madrid Fault, and he has found evidence of other large earthquakes in the past in addition to those in 1811 and 1812. So we know that this is an active and a repetitively active fault zone. Probably we are talking in terms of at least tens of thousands of years over which it's going to be active.

Mr. BATEMAN. So the fault has not been corrected by the 1811-12 phenomenon. Thank you.

Mr. GORE. Congressman McKay.

Mr. McKAY. Thank you, Mr. Chairman.

One of the things that I would like to pursue is the evidence, as I understand it, that an earthquake in the East would be potentially much more damaging than one in the West, that the shock would travel further, and so forth. What is the explanation for that?

Dr. NUTTLI. I think we are in a better position to give you a quantitative answer of how we can give you numerical differences in the transmission of energy between the East and the West, but we cannot give you the ultimate explanation of why there is a difference. We have some theories and speculation.

The rocks in the West are younger, they are higher temperature perhaps, they are more broken up by faults and they are folded, so that the path is not so uniform for the waves to travel, compared to the very old rocks—the crustal rocks of the East. That's one explanation.

The other explanation comes from studies of the Moon. The Moon also propagates seismic waves very efficiently. And the explanation for that is that the lunar rocks are very dry. So perhaps there is a difference in microscopic water content in the East and the West, the East being drier than the West. But we would have to do deep drilling again to be able to confirm it or reject this hypothesis.

Mr. McKAY. Thank you.

Thank you, Mr. Chairman.

Mr. GORE. Well, thank you.

We've got a lot of work to do then in the area of more research and more preparation.

I take it that you would agree, Dr. Johnston, that communities within the vicinity of the New Madrid Fault need to take a closer look at the work that has been done in this area in making their own preparations; would you agree with that?

Dr. JOHNSTON. I certainly would. I would agree wholeheartedly.

Mr. GORE. And summarizing again your earlier statements, you cannot predict when a major quake will occur. You can state that it is almost inevitable that—or that it is inevitable that a large quake will occur, but you can't say when, but the odds of it occurring increase with each passing year; is that fair enough?

Dr. NUTTLI. That is correct. And if you tell us when it will happen, we can tell you pretty much what will happen as well.

Mr. GORE. You mean the amount of energy released?

Dr. NUTTLI. The amount of energy released and the damage to the surrounding communities.

Mr. GORE. And if it occurred right now, it would be probably around 7.6 on the Richter scale?

Dr. NUTTLI. That's correct.

Mr. GORE. Is that correct?

Dr. NUTTLI. That's correct.

Mr. GORE. And the damages that would be associated with 7.6—

Dr. NUTTLI. It would extend out to distances of at least 300 miles radius.

Mr. GORE. The damages would extend 300 from the—

Dr. NUTTLI. From the—

Mr. GORE [continuing]. Epicenter.

Dr. NUTTLI [continuing]. Epicenter. That's correct.

Mr. GORE. And what would the damages include, with an earthquake of that size?

Dr. NUTTLI. Well, close in, you would have collapse of structures and you would probably have loss of life and many injuries. As you go farther away, the damage becomes smaller, becomes less the structural damage and more of the nonstructural or architectural type. There would be widespread damage to chimneys, chimneys going down over almost that entire area of 300 miles radius. And that brings in the potential for fire if you attempt to use a furnace or a fireplace and you have an obstructed chimney. And fire, as we know, often accompany earthquakes, and they oftentimes cause more damage than the earthquake itself. That is just one type of damage.

Waterpipes can be broken, you'll have cracks in walls in the structure, you'd have a lot of furniture overturned, light fixtures perhaps falling down which can injure and kill people at great distances away from the earthquake. All of these things are very likely to happen.

Mr. GORE. Electricity and——

Dr. NUTTLI. Power failures.

Mr. GORE [continuing]. Gas lines disrupted, is that——

Dr. NUTTLI. That's correct.

Mr. GORE. All right. Well, we're going to go into some of these matters in more detail with later panels. I want to thank you three for getting us off to a good start in this hearing, and you are welcome to stay for the rest of the hearing, if you like. We appreciate your testimony here. Thank you very, very much.

Mr. GORE. I want to call our second panel now: Dr. Samuel Speck, Associate Director of State and Local Programs and Support with the Federal Emergency Management Agency; Dr. Carl Hall, Acting Assistant Director for Engineering with the National Science Foundation; and Dr. John Lyons, Director of the National Engineering Laboratory with the National Bureau of Standards; and he is accompanied by Dr. Richard Wright, Director of the Center for Building Technology at the National Bureau of Standards.

I also want to acknowledge the presence in the room today of Mr. Lacy Suiter, chairman of the Central U.S. Earthquake Consortium, and he is here along with his assistant, Tom Durham, in the audience. And he heads the Tennessee Office of Emergency Management as well. We're delighted to have them as guests.

Without objection, your full statements will appear in the record at this point. If you want to summarize some portion of them, feel free to do so.

Dr. Sam Speck, we'd like to begin with you and FEMA's viewpoint. Please proceed.

STATEMENTS OF DR. SAMUEL W. SPECK, ASSOCIATE DIRECTOR, STATE AND LOCAL PROGRAMS AND SUPPORT, FEDERAL EMERGENCY MANAGEMENT AGENCY, WASHINGTON, DC; DR. CARL W. HALL, ACTING ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION, WASHINGTON, DC; AND DR. JOHN W. LYONS, DIRECTOR, NATIONAL ENGINEERING LABORATORY, NATIONAL BUREAU OF STANDARDS, WASHINGTON, DC, ACCOMPANIED BY DR. RICHARD N. WRIGHT, DIRECTOR, CENTER FOR BUILDING TECHNOLOGY, NATIONAL BUREAU OF STANDARDS

Dr. SPECK. Thank you, Mr. Chairman and members of the committee. My name is Samuel W. Speck and, at the Federal Emergency Management Agency, I am Associate Director for State and Local Programs and Support. I am pleased to have the opportunity to appear before this joint meeting of the two subcommittees and to have the opportunity to focus on what FEMA is doing to lessen the threat to lives and property from earthquake hazards throughout the United States, with particular emphasis upon Central United States.

In these remarks, I'm simply going to summarize my testimony and, frankly, add some things beyond my oral testimony as prepared. My testimony will be given to you in substantially expanded form for the record.

The creation of the National Earthquake Hazards Reduction Program, or NEHRP, 7 years ago was a major milestone in this country's efforts to identify and assess the hazards related to seismic events and to reduce the loss, destruction and disruption caused by those events.

In creating the National Earthquake Hazards Reduction Program, Congress brought together the research programs, already well underway, of the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards with the activities of FEMA to form an integrated and comprehensive Federal program. FEMA's overall mission is to coordinate the Federal emergency management activities—that has to do with mitigation, preparedness, response and recovery—or as Congressman Brown was noting, all types of emergencies and disasters, natural and man made—and to provide technical and financial assistance to State and local governments in carrying out their emergency management programs. With this in mind, Congress designated FEMA as the lead agency for the National Earthquake Hazards Reduction Program, with the responsibility for developing and leading and coordinating this program.

To meet the leadership challenge, FEMA created and chairs the Policy Coordinating Committee composed of senior policy-level officials from the principal agencies—that is FEMA, the Geological Survey, the National Science Foundation, and the National—the NBS, all of which are here—and also created the Interagency Coordinating Committee of the National Earthquake Hazards Reduction Program, composed of the principal program managers. These are the management committees of the National Earthquake Hazards Reduction Program, and are intended to provide guidance on overall earthquake program policy issues, oversee planning, budg-

eting, evaluation processes, and to resolve operational issues facing the agencies in meeting the goals of the National Earthquake Hazards Reduction Program.

I think it's perhaps useful—and this is a departure from—from my formal oral testimony—to sort of put together the overall National Earthquake Hazards Reduction Program, what are the elements in the overall program, and then you will be looking as each of us talk about the particular components for which we have primary, although always shared, responsibility.

The first is, as previous speakers in the previous panel have indicated, hazard assessment and delineation, just what's the nature of the hazards that we are facing together. A second involves the earthquake prediction research. And that's a major element in the National Earthquake Hazards Reduction Program. Third then involves seismic design and engineering research, how do we deal with the problem in terms of the various structures, whether it be bridges or lifelines or buildings or ports.

Then we have, fourth, preparedness planning and hazard awareness or education, education of public officials, and education of the public at large. Here we are looking at earthquake mitigation strategies. This involves a Federal response plan. It involves State and local preparedness. It involves earthquake education and information transfer, and it involves what you've already heard about in social response research.

And, finally, as a part of an overall program, you have very fundamental studies, studies of tectonic plates and these kinds of things, in addition to the overall comprehensive earthquake program.

In this context, the responsibility for implementing FEMA's National Earthquake Hazards Reduction Program rests with the Earthquake and Natural Hazards Program Division, and I have the chief of that division with me this morning to also assist in responding to any questions that you may have.

Our program focuses on four principal elements: First, seismic design and construction; second, State and local earthquake hazards reduction programs; third, public awareness and education; and fourth, Federal response planning. While I will briefly touch on each of these, it is important to keep in mind that, throughout this discussion, that these elements have application in all seismic risk areas throughout the Nation and are by no means exclusive to California, even though a great deal of past research may have taken place in that area.

Another point to remember is that the Earthquake Hazards Reduction Program does not exist in a vacuum. It's being carried out in concert with FEMA's other hazards reduction programs through the implementation of the integrated emergency management system, the IEMS system. Under IEMS, FEMA is providing funding and technical assistance to State and local governments to enhance their overall emergency management capability to prepare for and respond to the full range of natural and man-made hazards, including nuclear attack. The majority of this funding and the technical assistance is provided by the Civil Defense Program. The projects and activities funded by this Civil Defense Program

must contribute to, and in no way detract from, a nuclear attack preparedness, according to the statute set forth by Congress.

However, because of the many common functions that must be performed in the event of an earthquake or other hazards, including nuclear attack, such as informing the people of what to do and where to go, providing shelter, food, water, medical services, direction and control of emergency operations, earthquake preparedness benefits substantially from the agency's ability to integrate its several hazard-specific programs.

If I might depart, I would point out that, for example, we spend something in the neighborhood of \$56 million a year, the majority of which goes to State and local governments to fund general emergency management programs. In addition to that, in our State direction and warning control, we provide funding for emergency operating centers, which would be critical in the event of a major earthquake. We provide assistance for communications. We provide—we're working with the State and local governments in the area of coordination of emergency services, medical services, fire, and the like. So that the IEMS Program is a critical element in building a long-term capability.

It's important that we do look on these things in the long run on a multihazard basis. There was one community in Utah, for example, as it was seeking to provide protection in the event of an earthquake, dutifully put its operating room of its hospital below ground. The only trouble was there also happens to be a dam upstream from that town, and I wouldn't want to be in that operating room if you had a major earthquake in that area. It's important that we do look at these things on a multihazard basis. And indeed, one of the things FEMA's been doing is have a multihazard research program in Utah.

What we're doing in the IEMS process at the present time—in the IEMS process, we developed guidance in 1983, we are testing that in 1984, and expect to move to full implementation in 1985. And what that has involved nationally is working with State and local governments to, first of all, perform hazard vulnerability assessment. And second, on the basis of that hazard vulnerability assessment, to do in each community and on a statewide basis a capability assessment. You do your hazard vulnerability analysis, then your capability assessment. On the basis of that, you can then do your preparedness planning, and you look at your delta between where you are and where you need to be. And out of that, we are working with communities and States to develop multiyear development plans, so we can lay out over a period of time where we want to go and where Federal resources will be best spent in helping assist State and local governments to develop the capability to respond to all kinds of disasters, including earthquakes.

Some specific examples include the Emergency Management Assistance Program funded in part by the Civil Defense budget. It provides funds to establish and maintain emergency management infrastructure at the State and local levels of government. It is this infrastructure that supports mitigation, preparedness, response and recovery activities concerning all hazards, including earthquakes. Also the survey of facilities to determine their capability to provide shelter in the event of nuclear attack has been expanded to look at

the value of these facilities in the event of an earthquake or other hazards such as hurricanes.

And I might again depart from my remarks to point out that, when you're dealing with a hazard like earthquake where it is so difficult to project when it might happen—whether it would happen very soon, in the near frame, or whether you are really talking appears what it to average, perhaps 6 or 700 years between the major earthquake type of 1811-12 in the New Madrid area. It, frankly, is going to be a difficult thing, if we focus on earthquakes alone in terms of emergency preparedness, to keep people charged up to deal with that one thing. And that is why we in FEMA feel that it is so important to integrate in the long run into a comprehensive Integrated Emergency Management System, so that when you're exercising your system to deal with fire or a chemical spill, or whatever else, you're also keeping it honed up to deal with the kind of emergency functions that would have to be performed in the event of an earthquake.

Looking at the first major activity, seismic design and construction, in 1755, Cape Ann, MA experienced an earthquake intensity of 7 on the modified Mercalli scale. An observer near Boston noted that the Earth moved violently like waves on the ocean, making it necessary to cling to something to prevent being thrown to the ground. However, being thrown to the ground is not the major threat during an earthquake; most deaths and injuries result in the collapse of structures.

With the assistance of the NBS, the NSF, and the USGS, we are working to reduce this threat from Federal and non-Federal construction in new and existing buildings as well as lifelines. These activities will result in design standards, practices, and recommended provisions and manuals for various users in the construction industry. For example, the National Earthquake Hazards Reduction Program recommended seismic building provisions which focused primarily on new construction will be available this summer. We expect it to be a major assistance to the design professions.

In coming years we will initiate activities to produce companion products for existing construction in lifelines. For example, in fiscal year 1985, we are going to be doing that with lifelines.

State and local earthquake hazards reduction program is the second major element in FEMA's area of responsibility. Supplementing IEMS, we provide through the Earthquake Hazards Reduction Act financial support for earthquake hazards reduction projects in a number of high-risk and high-population areas. These include central United States; upper New York State; Puerto Rico and the Virgin Islands; Charleston, SC; Boston, MA—in addition, Utah, Alaska, Hawaii, Washington State and California.

Typically, FEMA's State and local projects follow a sequence of tasks which begin with hazard identification and continue through the stages of vulnerability assessment, mitigation, preparedness planning, public awareness and education and, ultimately exercises.

Earthquake threats are most commonly associated with the west. Because of the frequent occurrence of moderate earthquakes and of well-known faults, most people tend to think of California as the

Nation's earthquake center. The attention is reinforced by the 1980 National Security Council report estimate that a great earthquake in southern California could result in up to—and in that particular case, I would probably want to put that at 14,000 rather than 20,000 deaths, and \$70 billion in damages.

Let me say, however, that you have to be very careful in talking—and Congressman Brown will certainly know this from California—depending on where on the San Andreas Fault or some of the adjacent faults you are talking about, and the loss could be considerably higher as you combine some of those areas, both in terms of property and in terms of life. Also, you get an enormous variation according to the time of day. And you can double and triple the loss of life depending on what time of day an earthquake takes place.

This report was a major impetus to the creation of the Southern California Earthquake Preparedness Project, known as SCEPP, a cooperative effort between the State of California and FEMA. SCEPP's major objective has been to the enhancement of earthquake preparedness in southern California, while specifically developing a prototypical planning process and planning tools, for example, planning guidelines for cities that would serve as a model for other high-risk regions throughout the Nation.

As part of the Central United States Earthquake Workshop that we are having with CUSEC in the first week in June, there will be a half-day briefing on SCEPP at the conclusion of that workshop to look at the possibility for transferring the results of the findings that FEMA and California have jointly funded to the Central United States Earthquake Project area.

In addition to the risk in California, a damaging earthquake occurs somewhere in the eastern United States on the average of about every 25 years, and a large to great earthquake about every 50 to 100 years. In fact, the greatest earthquake to occur in the co-terminous United States struck New Madrid, MO. Three great earthquakes, plus 203 damaging aftershocks struck along the New Madrid Fault system in the winter of 1811 and 1812. The least of these virtually destroyed the town of New Madrid, with most structures collapsing from the first shocks as the town sank 15 feet. Liquefaction caused by earthquakes created a 25-square-mile area covered by 3 feet of extruded sand. The Mississippi River was reported to have flowed upstream. Windows and doors, we are told, rattled here in Washington, DC, and the shocks rang church bells as far away as Boston.

FEMA began its earthquake preparedness project in the Central United States by contracting with the USGS to perform a hazard identification based upon the 1811-12 events. This study allowed for the first vulnerability study, six cities in Central United States—Evansville, IN; Paducah, KY; Poplar Bluff, MO; Memphis, TE; Little Rock, AR; and Carbondale, IL.

While these studies will allow for the initiation of preparedness planning, they also underscore the regional multi-State aspect of the Central United States earthquake hazard. If the New Madrid earthquake were to recur today, 21 States would experience damaging earthquake intensities, on the Mercalli scale between 7 and greater. The area of the worst intensities, up at 9 or greater, would

cover parts of seven States. These States are Indiana, Illinois, Missouri, Arkansas, Mississippi, Tennessee, and Kentucky, and are the ones that formed the Central United States Earthquake Consortium, or CUSEC, in November of 1983.

FEMA contracted with CUSEC for the period of April 1984 through October of 1985 for the consortium to do the following: establish a CUSEC office to coordinate consortium activities; develop a 5-year plan from the regional multi-State perspective to implement the National Earthquake Hazards Reduction Program in the seven-State area; establish technical work groups, seismic safety organizations and assist member States to develop mutual aid agreements; hire an executive director and needed support staff; and arrange to conduct a National Earthquake Conference in St. Louis scheduled for June 2 through 5.

The third and—as I draw to a close here—major area of activity, public awareness and education. FEMA places great importance on public awareness and education programs because they are geared to help individuals, families, and neighborhoods, as well as State and local governments. Materials developed through these programs have a self-help approach, and provide information on preparing for an earthquake, how to survive one, how to be self-sufficient for 72 hours after a quake when the outside help is least likely to be available.

And, Mr. Chairman and members of the committee, I have brought with me some of the materials which we are currently testing, working with the Red Cross and working with some of the groups that have already been represented here this morning on the previous panel.

FEMA has developed model earthquake information products for use by State and local governments, volunteer organizations, civic groups, business, and the general public. FEMA supports two pilot earthquake education centers, one in South Carolina and another in Tennessee. The goals of these centers are to increase community awareness of earthquake risk and increase awareness of life-protecting actions during and after an earthquake. We are currently assessing all our awareness and education activities to ensure that all audiences are or will be reached with appropriate earthquake education materials.

Finally, Federal response planning. The development of a Federal plan for immediate life-saving, life-protecting support to State and local governments affected by a catastrophic earthquake continues to be a high priority within FEMA's Program responsibilities. Along with FEMA, 21 other Federal agencies are participating in this planning effort. The plan identifies 14 emergency support functions for which it is anticipated that State and local resources would be inadequate to respond to the immediate effects of a catastrophic earthquake.

And let me say that we are speaking particularly of the kind of earthquake that we had in 1811-12 period in New Madrid, or the kind that might be anticipated in California, or that we endured in Alaska perhaps to a lesser degree.

Although the functions used in developing the plan have been based primarily on assessment of needs identified in California, where vulnerability studies and preparedness planning are well de-

veloped, the framework of policies and mechanisms in the plan are designed to ensure that the Federal Government is prepared to support State and local governments in any area of the country in which a catastrophic earthquake might occur.

The draft plan will be tested in a headquarters only exercise during August of 1984. RESPONSE 84 will test the coordination capabilities of Federal agencies and the adequacy of the Federal part of the plan based upon a simulated catastrophic earthquake on the southern San Andreas Fault. The headquarters exercise will be followed by a regional exercise in early 1985. FEMA will then initiate response planning in other regions of the country later in 1985. So we are going to test that in what will ultimately be a full-field exercise in late summer of 1985.

If an earthquake of a catastrophic nature were to occur now in any area of the country, the national plan will provide a framework for Federal support at the regional level. While California has been used as a source of information and a testing ground, the national plan is not in any way limited to that area in its design or application.

Thank you, Mr. Chairman and members of the committee. I'd be glad to respond to any questions at the appropriate time.

[The prepared statement of Dr. Speck follows:]

Statement of

Dr. Samuel W. Speck

Associate Director, State and Local Programs and Support
Federal Emergency Management Agency

I am pleased to appear before this joint session of the House Subcommittee on Investigations and Oversight and the Subcommittee on Science, Research, and Technology to discuss the earthquake threat to the Central and Eastern United States and what the Federal Emergency Management Agency (FEMA) is doing to prepare for possible events in that part of the country to lessen the risk to lives and property.

INTRODUCTION

The creation of the National Earthquake Hazards Reduction Program (NEHRP) 7 years ago was a major milestone in this country's efforts to identify and assess the hazards related to seismic events and to reduce the loss, destruction, and disruption caused by those events. In creating the NEHRP, Congress brought together the research programs, already well underway, of the U.S. Geological Survey (USGS), National Science Foundation (NSF), and the National Bureau of Standards (NBS) with the activities of the Federal Emergency Management Agency (FEMA) to form an integrated and comprehensive national program. FEMA's overall mission is to coordinate Federal emergency management activities (preparedness, response, recovery, and mitigation) for all types of disasters - natural and manmade - and to provide technical and financial assistance to State and local governments in carrying out their emergency management programs. With this in mind Congress designated FEMA as the lead agency for the NEHRP, with responsibility for developing, leading, and coordinating this national program.

FEMA has provided leadership to the Program in several ways.

- FEMA has stimulated the creation of the Policy Coordinating Group, composed of senior policy level officials of the four principal agencies (USGS, NBS, NSF, and FEMA), to provide guidance on overall program policy issues and to oversee the NEHRP planning, budgeting, and evaluation processes. The FEMA chairs this important coordinating forum.
- FEMA established and chairs the Interagency Coordinating Committee (ICC) of the NEHRP. The ICC is composed of program-manager level representatives of the four principal agencies assigned responsibilities under the Program and other departments and agencies which conduct earthquake related programs. The ICC provides a setting for the staff to meet regularly and resolve the operational issues facing the agencies in meeting the goals of the NEHRP.
- FEMA chairs the Earthquake Work Group in support of the Emergency Mobilization Preparedness Board (EMPB). The EMPB was created by President Reagan to ensure that the nation would be capable of responding effectively to major peacetime and wartime emergencies. The Earthquake Work

Group is addressing national mobilization and preparedness issues associated with the consequences of a catastrophic earthquake.

- FEMA has established an Earthquake and Natural Hazards Programs Division within the Office of Natural and Technological Hazards to provide a focus for earthquake related activities within our agency.
- FEMA, working through the ICC and Policy Coordinating Group mechanisms previously explained, is preparing the 5-Year Plan for the National Earthquake Hazards Reduction Program. The Plan, which details the activities to be undertaken by the principal agencies, is being developed within the framework of the Administration's budget ceilings for FY 1985 through FY 1989.

FEMA's EARTHQUAKE PROGRAM

In addition to the FEMA's leadership activities, many of which involve coordination with the other members of this panel, FEMA's earthquake program is essentially comprised of the following four elements: Seismic Design and Construction, State and Local Earthquake Hazards Reduction Programs, Public Awareness and Education, and Federal Response Planning. An explanation of each of these elements and how they relate to the earthquake threat to the Central and Eastern United States follows.

Seismic Design and Construction

The partial or total collapse of structures from an earthquake is the main cause of earthquake injuries and deaths. However, casualties can occur not only from the buildings themselves but from the secondary effects of failed lifelines, such as fires caused by ruptured natural gas lines. In order to lessen these threats to human life, FEMA supports activities which can enhance the seismic safety of new and existing buildings as well as lifelines. These activities, which consider both Federal and non-Federal construction, will result in design standards, practices, recommended provisions, and manuals for the different users in the construction industry. These products, which will serve as the basis for long term earthquake mitigation programs, will be disseminated by suitable means to governmental and private-sector organizations who are responsible for their adoption into building codes and to the design professions for their use.

The seismic safety requirements for buildings constructed or used by Federal agencies, as well as buildings constructed under various Federal grant, lease, and regulatory programs, should be consistent. To satisfy this need, the Interagency Committee on Seismic Safety in Construction (ICSSC), representing all Federal construction agencies, was created in 1979 and is chaired by the NBS with funding support from FEMA. By January 1981, the ICSSC had formulated and issued draft seismic standards for Federal

buildings applicable to new structures. In issuing the document, the ICSSC urged Federal agencies to use these provisions in their normal mission-oriented construction activities.

The ICSSC is now drafting a recommendation to FEMA on the most suitable process and procedures to ensure a wider acceptance and application of the standard. FEMA, with technical support from the NBS, is committed to a long-range program in this area.

In parallel with these Federal activities are the activities of the Building Seismic Safety Council (BSSC), an independent, voluntary body established under the auspices of the National Institute of Building Sciences. The BSSC enhances public safety by providing a national forum to foster improved seismic safety provisions for use by the building community in planning, designing, constructing, regulating and using buildings.

Since its establishment just 5 years ago, the BSSC, with funding provided by FEMA, has undertaken a trial design program directed toward the creation of a technically sound resource document that can be used by the voluntary standards and model code organizations, the building community, and the public as the foundation for achieving improved seismic safety of buildings.

The program entails a multiyear, multiphased effort to assess the viability of (including relevance, clarity, completeness, and practicability) and to refine as necessary, the Applied Technology Council's Tentative Provisions for the Development of Seismic Regulations for Buildings into a new document, the NEHRP Recommended Seismic Building Provisions. The program also is aimed at establishing the technical validity of the provisions; the identification of the economic and social impact of their implementation; the generation of objective information for use in the future resolution of disputes concerning specific provisions; and the conduct of a long-range program to encourage the adoption of the NEHRP recommended provisions by the design professions, the code- and standard-writing organizations, and State and local regulatory bodies.

BSSC has subjected the tentative provisions to a trial design process involving almost 50 buildings of different size, shape, occupancy, and construction type in nine cities, six of which are east of the Rockies. The nine cities are Memphis, St. Louis, Charleston, New York, Chicago, Fort Worth, Phoenix, Los Angeles, and Seattle. The NEHRP Recommended Seismic Building Provisions are scheduled to become available this summer, with BSSC membership approval expected in about 12 months.

As described, the activity to date has been directed primarily at addressing new construction practices; however, attention to existing construction is imperative. Spurred by tax credit incentives, the rehabilitation of structures-historical and nonhistorical, residential, and commercial-is proceeding at a rapidly increasing pace. Most rehabilitation work is done

without a set of generally accepted and applied seismic building standards and practices. This means that in areas of high and moderate seismic risk throughout the country, hazardous buildings are being given additional years of occupancy, thus exacerbating an already serious condition.

Yet, there is a considerable body of engineering and architectural knowledge on how to repair and retrofit structures to improve their seismic resistance. Additionally, practical experience resulting from the application of building codes incorporating seismic provisions by a few municipalities (e.g., the City of Los Angeles) is being accumulated. There is, therefore, a sufficient base of knowledge to proceed with a comprehensive, multiyear effort to abate the seismic hazards created by old buildings. FEMA is currently in the process of contracting for the development of a comprehensive and detailed plan for this hazard abatement program. The objective of this plan is to provide FEMA (and, possibly, other Federal agencies) with detailed guidelines, a suggested implementation process and identification of the resources required to carry out this mitigation program.

No less important are the lifeline facilities. FEMA will, during FY 1985, acquire a plan similar to that described above for assessing existing structures that will provide a basis for long range planning to deal with the lifeline issue.

In the Eastern and Central United States, awareness of the need to incorporate seismic standards into design and construction practices for new and existing buildings and lifelines has been virtually non-existent. The dangers of this have been aptly underscored by the Coalinga, California earthquake of 1983 which caused significant partial and total collapses in the town's old unreinforced structures. In fact, the April 24, 1984, earthquake near San Jose, California demonstrated that buildings and lifelines constructed with seismic safety considerations resisted the seismic loads and decreased the earthquake's damaging effects. The seismic design and construction products currently being developed with FEMA support can and will be applied to the Central and Eastern United States.

State and Local Earthquake Hazards Reduction Program

Under FEMA's Integrated Emergency Management System, FEMA provides funding and technical assistance to States and local governments to enhance their overall emergency management capability to prepare for and respond to a full range of natural and manmade disasters including nuclear attack.

The majority of this funding and technical assistance is provided by the Civil Defense program. The projects and activities funded by the Civil Defense program must contribute to -- and in no way detract from -- nuclear attack preparedness. However, because of

the many common functions that must be performed in the event of an earthquake or other hazards, including nuclear attack -- e.g., informing the people of what to do and where to go; providing shelter, food, water, medical services; direction and control of emergency operations -- earthquake preparedness benefits substantially from the Agency's ability to integrate its several hazard-specific programs.

Some specific examples include the Emergency Management Assistance Program, funded as part of the Civil Defense budget, that provides funds to establish and maintain an emergency management infrastructure at the State and local levels of governments. It is this infrastructure that supports mitigation, preparedness, response, and recovery activities concerning all hazards -- including earthquakes. Also, the survey of facilities to determine their capacity to provide shelter in the event of a nuclear attack has been expanded to look at the value of these facilities in the event of an earthquake and/or other hazards.

FEMA is also supporting a range of earthquake specific activities in high-to-moderate-hazard States and localities identified by the USGS and FEMA. These activities typically follow a logical sequence of tasks that begin with an assessment of past and potential seismic activity in the area. Based on these assessments, vulnerability or loss studies are made to estimate primary and secondary earthquake effects, the number of possible casualties, and potential damage to critical and or special facilities and lifelines needed for immediate response operations. Using data from these analyses, FEMA assists the States and local governments to undertake preparedness, response, recovery and mitigation planning and to integrate this planning into their overall emergency management programs. Throughout this process, the State and local governments are encouraged to implement public awareness and education programs.

The earthquake threat is most commonly associated with the West, where there is a large to great earthquake about every 50 to 100 years. Ongoing, FEMA-supported, State and local earthquake hazard reduction programs in this broad geographical region include California, Salt Lake City, Puget Sound, Alaska, and Hawaii. However, while not as severe as in the West, a damaging earthquake occurs somewhere in the East about every 25 years. For this reason, FEMA is supporting similar programs in the Central United States, New England, South Carolina, Upper New York State; and the Caribbean. Before describing these latter programs more fully, it is appropriate to briefly discuss FEMA support of the Southern California Earthquake Preparedness Project (SCEPP).

SCEPP is a cooperative endeavor between the State of California and FEMA and was established in September 1980 in response to a study by the National Security Council entitled An Assessment of the Consequences and Preparation for a Catastrophic California Earthquake: Findings and Actions Taken. This report

cited conclusions of earth scientists that the probability of an eight-plus (Richter) magnitude event was about 50% over the next 30 years along the section of the San Andreas Fault that runs closest to the Los Angeles metropolitan area. It concluded that there could be from 3,000 - 20,000 deaths, many more injuries, and from \$20 billion to \$70 billion in property damage. This area includes about 160 cities and generates about 7% of the Gross National Product.

Toward SCEPP's goal of stimulating earthquake preparedness in its five-county area, its major objective has been the development and testing of a prototypical planning process and prototypical planning tools (such as planning guidelines for cities) that would not only increase earthquake preparedness in the areas in which they were developed, but would serve as a model for other high risk regions throughout the United States.

The SCEPP planning process has now been developed, and the planning tools and other materials produced are beginning to be transferred to other jurisdictions in California. SCEPP has already helped to achieve an increased level of preparedness in the jurisdictions with which it has established its planning partnerships to develop the above mentioned materials. It is also now evident that its experience and the materials developed will have applicability to Central and Eastern States as well. FEMA is developing a system to make this material available in these areas.

Central United States - Three great earthquakes, plus 203 damaging aftershocks, struck New Madrid, Missouri in the winter of 1811 and 1812. The earthquakes are estimated to have had surface-wave magnitudes (M_s) of 8.6, 8.4, and 8.7. Only a few persons were known to have died in the thinly populated area. However:

- the Mississippi River was reported to have run upstream, at least for a time,
- windows and doors rattled in Washington, DC, and the shocks rang church bells 1000 miles away in Boston,
- liquefaction, caused by the shocks, created a 25 square mile area covered by 3 feet of extruded sand, and
- in New Madrid most of the structures tumbled down and the site of the town sank 15 feet.

The recurrence of the 1811-1812 "New Madrid Earthquakes" could potentially affect 21 States with damaging ground shaking intensities (Modified Mercalli intensity VII or greater). However, FEMA's Central United States Earthquake Preparedness Project (CUSEPP) planning area currently includes the seven States (Arkansas, Indiana, Illinois, Kentucky, Mississippi, Missouri, and Tennessee) which would experience the most damaging ground shaking intensities of Modified Mercalli-IX and above.

In 1981, FEMA requested the USGS to identify the geographical area susceptible to seismic shaking based on a great earthquake

comparable to the 1811-1812 events. The USGS completed and published its Estimation of Earthquake Effects Associated with a Great Earthquake in the New Madrid Seismic Zone two years later. As a supplement to previous USGS identification of general ground shaking intensities for the entire Central United States, this report contained specific intensity mapping for six cities--Carbondale, Illinois; Evansville, Indiana; Little Rock, Arkansas; Memphis, Tennessee; Paducah, Kentucky; and Poplar Bluff, Missouri.

This specific intensity mapping formed the basis for undertaking a vulnerability study of these six cities, which was completed in draft form in November 1983. Since the study employed a methodology for assessing losses which FEMA had not previously used, the Agency initiated a review of the study by the USGS, NBS, NSF and other experts in the field in order to assure that the study was a technically sound product. Through this review it was determined that, while the methodology was sound and applicable to the Central United States, a lesser magnitude but more likely earthquake scenario than the great 8.6 earthquake scenario should be included. This revision, along with minor editorial changes, will be incorporated and the study's publication is expected in the fall of this year.

Coinciding with FEMA's efforts in hazard and vulnerability assessment is the Agency's financial support to the States of the current CUSEPP planning area. In FY 83, FEMA provided limited funding to each of these seven States to: (1) initiate their work on State specific 5-year work plans for earthquake hazard reduction efforts, (2) establish State Seismic Advisory Boards and (3) participate in the formation of a multistate consortium on the earthquake hazard in the Central United States. These individual activities are being continued in FY 84 for each State.

The regional nature of the earthquake hazard in the Central United States is the primary reason for the creation of a multistate consortium. In November 1983, a Board of Directors from the seven States formed the Central United States Earthquake Consortium (CUSEC) to coordinate and manage their interstate activities. In April 1984 FEMA contracted with the CUSEC to support this work and also to (1) develop a 5-year workplan for the multistate efforts (2) hire an executive director with staff (3) establish a physical office with support capabilities and (4) arrange and conduct a National Earthquake Conference in St. Louis from June 2-5, 1984. Funding for this totals \$298K and the period of performance runs through October 1985.

The importance of the CUSEC to the Central United States effort should not be underestimated. The 5-year workplan will allow FEMA to disburse further State specific funds in FY 1985 and beyond in a clear and coordinated pattern, avoiding conflicting efforts on the part of any States. It will also allow for measured and purposeful funding for further hazard identification

and vulnerability assessment in the Central United States. In all these efforts, FEMA will be working with and in support of the States involved.

New England - A 350 year record of seismic activity, including both the historic record and high quality instrumental data gathered over the past ten years, clearly document the earthquake hazard in Massachusetts. This long history includes many small and a number of more significant events. Perhaps more than any other events, the earthquakes off Cape Ann on November 9, 1727 and November 18, 1755 have served to classify eastern Massachusetts as an area with the potential to suffer future damaging earthquakes.

In June of 1981, the Commonwealth of Massachusetts initiated a seismic hazard assessment for the Boston area. Scientific information was provided by the project's Advisory Committee, comprised of volunteer faculty members from several local universities and private organizations. Ground-shaking intensity mapping was completed early in FY 1984, and a vulnerability study of the number of potential casualties and damage to lifelines and other critical facilities in the Boston area is now underway. FEMA plans to continue its financial support to Massachusetts through FY 1990 to accomplish the necessary preparedness and mitigation planning and public awareness programs.

While the activity to date has been primarily focused on the Boston area, this year FEMA is providing financial support for a planning council to further define the degree which earthquake hazard reduction activities should be expanded in the New England area. The council will consist of representatives across the full societal spectrum. FEMA plans to provide funding for additional vulnerability studies in New England in FY 1985 based on the geotechnical information of the area and the degree of support shown by State and local governmental decisionmakers for the high-risk areas. Preparedness planning would then be expected to begin in FY 1987, and mitigation planning in FY 1989.

South Carolina - A South Carolina Seismic Safety Consortium was formed by local initiative in late FY 1982 to promote seismic hazard awareness and serve as the focal point for preparedness activities in the State. The Consortium is comprised of five task groups; each group includes representatives of State and local government, professional associations, universities, and the public. In FY 1982, FEMA provided funds for completion of a task analysis, a needs assessment, and an inventory of existing data required prior to the conduct of the first phase of a vulnerability analysis, which was begun this year and will continue to receive funding through FY 1985. Preparedness planning is scheduled to begin in FY 1986, with completion scheduled for FY 1987. Mitigation planning will be funded in FY

1988 through 1990.

Again, it is important to emphasize the need for earthquake preparedness and mitigation throughout the region, not just the high-risk area defined by the Charleston, South Carolina, earthquake of 1886. Although the maximum damage was in an elliptical area of roughly 20 by 30 miles, centered at Summerville (about 18 miles northwest of Charleston), the earthquake was felt over the entire United States east of the Mississippi River, resulting in some broken dishes and cracked plaster 750 miles away in Chicago.

Upper New York State - This year FEMA will initiate funding for New York State as it begins the earthquake hazard reduction efforts in the north-central area of the State. Initially, the effort will center around the funding of a planning council comprised of representatives of the full societal spectrum. This council will define the future activities in this area. Vulnerability assessments are planned to commence in FY 1985, preparedness planning in FY 1987, and mitigation planning in FY 1989.

The Caribbean - Earthquake vulnerability studies for Puerto Rico/Virgin Islands are currently underway and are expected to be completed in FY 1985. Preparedness planning will be initiated in FY 1986 and continue through FY 1988. The mitigation planning effort will begin FY 1989. In April of this year, earthquake planning workshops were held to define the specific activities required to develop these plans. The work will be affected by such factors as the availability of geotechnical information and the degree of support decisionmakers and others will provide.

Public Awareness and Education

FEMA has developed model earthquake information products for use by State and local governments, volunteer organizations, civic groups and business. A "self-help" approach to these materials has been employed, designing them for easy adaptation at the local level so that they can be tailored to the special needs of the community. The materials contain instructions targeted at the family audience on what to do to prepare for earthquakes, how to survive a quake, and how to be self-sufficient for 72 hours following the quake. They are designed for people with little or no exposure to earthquakes and are particularly suited for non-California audiences for this reason.

A two-phase effort is underway with the American Red Cross, including development, pilot-testing and distribution of both print materials and two series of television public service announcements. One series will be oriented to central and eastern United States audiences. Publications distributed in

test areas include a family checklist, an earthquake drill, a home hazards hunt, a poster, a neighborhood guide, materials for youth program administrators, a school guide and a resource workbook. Test sites include New England, New York, Illinois, Indiana, Kentucky, Arkansas, Tennessee, Mississippi, Missouri, and South Carolina.

FEMA supports two pilot Earthquake Education Centers (EECs), one at the Baptist College in Charleston, South Carolina, and the other at the Tennessee Earthquake Information Center in Memphis, Tennessee. EEC goals are:

- ° increase community access to information on earthquake risk and life safety measures, and
- ° improve individual and community capability to take life-protecting actions during and following an earthquake.

An Earthquake Education Steering Committee has also been established within FEMA to develop a multiyear Earthquake Education Management Plan. The Plan will provide a basis for coordinating FEMA's, and possibly other agencies', earthquake education efforts.

Federal Response Planning

The development of a Federal plan for immediate lifesaving, life-protecting support to State and local governments affected by a catastrophic earthquake continues to be a high-priority within FEMA's program responsibilities. Along with FEMA, 21 other Federal agencies are participating in the planning effort. These efforts are maintained through the Subcommittee on Federal Earthquake Response Planning, which was formed in August 1982 under the auspices of the ICC of the NEHRP.

The Third Draft of the National Plan for Federal Response to a Catastrophic Earthquake has been written. The Plan identifies 14 emergency support functions for which it is anticipated that State and local resources would be inadequate to respond to the immediate effects of a catastrophic earthquake. Although the functions used in developing the Plan have been based primarily on assessment of the needs identified in California, where vulnerability studies and preparedness planning are well developed, the framework of policies and mechanisms in the Plan are designed to ensure that the Federal Government is prepared to support State and local governments in any area of the country in which a catastrophic earthquake might occur.

The draft Plan will be tested in a headquarters-only exercise during August 1984. Named RESPONSE 84, the exercise will be used to test the coordination capabilities of Federal agencies and the adequacy of the Federal part of the Plan based on a simulated catastrophic earthquake on the southern San Andreas fault. This

exercise at headquarters level will be followed by a regional exercise in early 1985. Again, the planning already completed in California will be used for this regional coordination exercise. Using the experience gained from the regional exercise, FEMA will initiate response planning in other regions of the country later in 1985. Rather than just focusing on the response required to a catastrophic earthquake, the planning will be integrated with overall assessment of needs to ensure a coordinated response capability at all levels of government when Federal assistance is necessary following any catastrophic event.

If an earthquake of a catastrophic nature were to occur now in any area of the country, the National Plan which has been developed would provide a framework for Federal support at the regional level. While California has been used as a source of information and a testing ground, the National Plan is not in any way limited to that area in its design or application.

Mr. GORE. Thank you very much, Dr. Speck.

We will hold our questions until the other panelists have spoken.

Dr. Carl Hall is the acting assistant director for engineering with the National Science Foundation. I'm pleased to welcome you, Dr. Hall. Please proceed.

Dr. HALL. Thank you Mr. Chairman.

I'm reporting for the two major activities within the National Science Foundation, one of those in the Engineering Directorate, and the other in the Directorate for Astronomical, Atmospheric, Earth, and Ocean Sciences.

I have with me two individuals, Dr. William Hakala and Dr. Thomas Wright, who are program directors in their respective areas, who would be available to answer more specific questions that may come up as a result of our discussion.

I thought for a change of pace we might use some slides which, in effect, will illustrate many of the points which have been made by previous speakers.

[Slide shown.]

Dr. HALL. Here we have a map of the United States which shows the history of earthquakes from whenever the history could record them, placed them on a map with various intensities. Although you may not be able to see the circles and the squares, there are circles interspersed among the squares which show a heavier intensity of earthquakes. And you can see these are spread throughout the United States, as was mentioned by some of the previous speakers, but which is quite impressive when you see it graphically on this map.

And although the greatest seismic hazard is presently believed to be on the west coast, recent concern has been expressed about the possible earthquakes in Eastern United States, similar to those you've heard several speakers previously mention. And we know that these major Eastern U.S. earthquakes differ from their western counterparts in several different ways, which have also been stated by previous speakers, but which are listed in my formal presentation which I will not repeat.

These factors have contributed to our lack of knowledge of the tectonic processes responsible for earthquakes in Eastern United

States. Thus, there is a general lack of awareness of the severity of the earthquake hazard in Eastern United States.

In the AAEO directorate, the fundamental earthquake studies element is supported primarily through the seismology program of the Division of Earth Sciences. Seismology is the primary method of studying the structure and physical properties of the earth's interior and of defining the plates making up the Earth's lithosphere. As such, seismology and other earthquake-related topics have constituted an important part of the program of this division for about 20 years.

Now, in the engineering directorate, the general objective of the Earthquake Hazards Mitigation Program is to conduct research which will result in improved design methodologies, which, in turn, will lead to minimizing property damage and will help to eliminate loss of life from potentially damaging earthquakes. For budget purposes, the Earthquake Hazards Mitigation Program is divided into the three general research areas of siting, design and societal response.

[Slide shown.]

Dr. HALL. Siting research seeks to determine from instrumentation and geotechnical data the nature of the strong ground motion causing shaking during earthquakes, as shown and demonstrated in this slide, to predict the distribution of strong ground motion at different sites, to understand the dynamic nature of soil and rock subject to strong shaking, and the interactions between the soil and the structures. Here you can see the more extensive damage closer to the epicenter, which perhaps is obvious, but which has been mentioned by previous speakers. And as we move out, there is less likelihood of severe damage.

Now, tied to the siting research is our design research program, which aims to develop procedures for performing dynamic analyses of proposed or existing structures under earthquake loadings.

Then we have the societal response research, which studies and evaluates measures that can be used to mitigate society's losses due to earthquakes, and also to study actions that communities can take to withstand earthquakes and other disasters with minimal impact on both life and property.

[Slide shown.]

Dr. HALL. Within each of the above objectives is research related to lifelines, facilities that are essential to orderly recovery following an earthquake.

The plate tectonic hypothesis has provided a good understanding for a number of the world's most active earthquake belts. Nevertheless, there has been relatively little work done on earthquakes which occur inside large lithospheric plates. That's the solid part of the Earth's crust that make up the surface of the Earth. The Eastern United States lies within the North American plate. Although intraplate earthquakes account for only a few percent of the world's earthquakes, a number of large and damaging shocks have occurred within various plates, including the earthquakes in Eastern United States.

It is crucial to know, for example, whether large shocks like those near Charleston in 1886 can occur at random anywhere within the North American plate, or whether such shocks occur

along specific tectonic features for which the seismic risk is much higher than other parts of the plate.

As an example of what is being done to understand the large historical shocks in the Eastern United States, I would like to briefly describe to you the results of a research project supported by NSF which may have relevance to the question of the ultimate cause of that 1886 Charleston earthquake. The project is known as Cocorp, Consortium for Continental Reflection Profiling, and consists of a consortium of five universities, Cornell, Rice, Dartmouth, Wisconsin and Princeton, with Cornell as the operating institution. The project uses seismic reflection profiling techniques to study the deep structure of the Earth's crust and upper mantle.

[Slide shown.]

Dr. HALL. In several recent studies, Cocorp has obtained reflection profiles in the southern Appalachians and the New England Appalachians, as shown in this slide. The results have very important implications for Appalachian geology, the process of continental growth, and for a possible mechanism for large earthquakes in the Eastern United States.

In particular, profiling in Georgia, North Carolina and Tennessee indicates that a thin sheet of older crystalline rocks has been thrust great distances over a layer of younger sedimentary rocks which formed the ancient continental margin of the land mass that was to become North America. So instead of earthquakes being confined to areas between the arrows that you see there, the earthquake could occur all along this subhorizontal thrust fault.

If this major shallow thrust sheet is a pervasive feature all along the east coast of the United States and the above hypothesis is correct, a Charleston-like earthquake could occur elsewhere on the eastern coast of the United States.

[Slide shown.]

Dr. HALL. A reoccurrence, of course, of these earthquakes could cause severe damage and loss of life. The energy absorption—or the attention—of geologic materials in the East is much less than in California, resulting in a much larger area being impacted by the earthquake, as shown by the contours of equal damage in this particular slide, with the areas of red, of course, the highest intensity of earthquake. But you can see the areas covered in the East are much greater for the same intensity than in the West.

In the 1976 Tangshan earthquake in the People's Republic of China, which was one of the most devastating in history—we have some of the damage that occurs. And the interesting thing is that the city of Tangshan lies on a plate similar to the Eastern United States, and without warning, with a magnitude of 7.9 an earthquake leveled most of the city, having a population of 1 million with fatalities estimated between 230,000 to 200 and—to 750,000 people.

[Slide shown.]

Dr. HALL. Unreinforced masonry structures, as shown by this slide, which are very susceptible to earthquake damage, collapsed under the strong ground motions, killing many people.

I believe the next slide shows a similar damage effect.

[Slide shown.]

Dr. HALL. This is the damage to the structures in Coalinga, CA, in May 1983. And many of the structures in Eastern United States are like these.

Next slide.

[Slide shown.]

Dr. HALL. Now this is a very impressive slide which depicts the result of liquefaction of the soil under the foundation. And what occurs is that, in certain soils with a certain moisture content, these soils become liquefied and no longer are stable. And in this case, the entire buildings just turned over.

The research conducted by the earthquake hazard mitigation grantees is generally applicable in all regions of the United States. Active research awards exist at approximately 65 different institutions, distributed in the approximate manner of one-third in California, one-third in Western States excluding California, and one-third to States east of the Mississippi River. This broad distribution of activities is entirely appropriate because graduates of the universities in these areas tend to work in all parts of the country and of the world.

An important element of the NSF Research Program is dealing with existing hazardous structures, including lifelines. Frequent earthquakes in California have kept State and local government officials sensitized to the earthquake risks and, therefore, new structures are designed with advanced seismic design procedures. Because of relatively infrequent large earthquakes in the Eastern United States, officials in these areas, until recently, have tended to overlook earthquake considerations. Thus, the reoccurrence of a large earthquake in the East could cause widespread property damage and loss of life.

Research is being conducted to find cost-effective methods to upgrade existing structures. Stanford University is conducting a study of the Boston area to determine the impact of regulations on upgrading hazardous buildings. Georgia Institute of Technology is assessing earthquake hazards in existing buildings in five southeastern cities—Memphis, TN; Atlanta, GA; Asheville, NC; Huntsville, AL; and Charleston, SC. A private sector firm, EQE, Inc., is developing a method to estimate earthquake damage in high-technology industries, and is using the electronics industry in Boston as the base. Cornell University is developing techniques to estimate building stock at risk, particularly in older cities. The Architectural Research Centers Consortium, Inc. is conducting a study on preservation of historic structures subjected to earthquakes and other national hazards. National Science Foundation recently joined with several other agencies to fund a workshop in Charleston, SC to make local and State officials aware of potential earthquake problems in their area.

Other examples of activities within NSF that are specifically related to earthquake problems in the East follow. NSF has funded the Earthquake Engineering Research Institute to conduct seminars in all areas of the country to familiarize engineers with design principles for earthquake regions.

Mr. GORE. Dr. Hall.

Dr. HALL. Uh-huh.

Mr. GORE. If I could interrupt you briefly—I apologize—we have a vote, or a quorum call and a vote, on the floor. With your indulgence, I'm going to have to recess for approximately 10 minutes, and then we will resume.

[Recess.]

Mr. GORE. The subcommittee will come back to order.

I was just saying it is fair enough for you to be out of the room, Dr. Hall.

Dr. HALL. Thank you.

Mr. GORE. We had two back-to-back votes, and I apologize for the inconvenience. It gets that way sometimes up here when we will have slow periods and then, all of a sudden, there is a big rush. It's sort of like tectonic plate activity. The pressure builds up and then bursts out.

Anyway, you were in the middle of your statement, so please go ahead.

Dr. HALL. Thank you very much.

[Slide shown.]

Dr. HALL. Other examples of activities within NSF that are specifically related to earthquake problems in the East follow. NSF has funded the Earthquake Engineering Research Institute to conduct seminars in all areas of the country to familiarize engineers with design principles.

[Slide shown.]

Dr. HALL. Recently, an award was made to SUNY-Buffalo to complete a 12-foot by 12-foot shake table. Shake tables are used for testing structures and other devices for earthquake conditions, to simulate earthquake conditions.

[Slide shown.]

Dr. HALL. The next slide shows the instrumentation associated with that previous shake table. On that shake table was a metal structure, a steel structure, which could be shaken at different amplitudes and—and frequencies of vibration to simulate earthquakes.

SUNY-Binghamton has installed and maintains a strong motion instrumentation array in the State of New York. And I should mention that the shake table, along with a lot of the installations for measurement, has been funded also by the State of New York, recognizing, I assume, the importance of knowing more about earthquakes in the Eastern area of the United States.

For a number of years, NSF has funded a specific type of research to make structures seismically resistant, namely base isolation, as shown in this slide.

[Slide shown.]

Dr. HALL. A base isolator consists of metal plates with rubber between them, like metal and rubber sandwiches.

[Slide shown.]

Dr. HALL. This concept has recently been incorporated into the design and construction of the Foothill Communities Law and Justice Center in San Bernardino County, in California, as shown in this slide, in which the footings are made up of base isolation support for the columns that will come and set on these footings. And the idea is that these base units, made up of metal and rubber, will

isolate the vibration of the Earth from the earthquake from the building so the building will remain standing.

The 1971 San Fernando earthquake emphasized the importance of seismic design for lifelines. Extensive damage resulted to underground water and sewer lines, gas pipelines, electrical substation equipment, communications systems, and transportation facilities. Seismic design criteria had been absent in such facilities previously. Because of the great length of such facilities, ground motion criteria applicable to conventional structures are not suitable. Research utilizing seismic risk analysis of network systems and economic principles has enlightened us on how such facilities respond in an earthquake environment. Despite significant advances in the last decade, the state of the art is still lagging well behind our understanding of the response of conventional structures. There remains an urgent need to expand the experimental data base for lifeline systems.

The critical nature of lifeline systems has generated a number of formal groups, the American Society of Civil Engineers, the Interagency Committee on Seismic Safety In Construction. This subcommittee held a workshop in Washington, DC, on March 20, which included participation by many agencies, Bell Laboratories and the Electric Research Power Institute. A joint meeting with Japanese counterparts was held in May. A workshop to define research needs in this area is to be held in California.

Because of the urgency in making preparations for a major earthquake, we have not been content with only reporting research results in our technical journals, but have attempted to accelerate the utilization of findings. This has required extensive interaction with other Federal agencies and, when appropriate, with State and local officials.

The researchers participating in the earthquake hazard mitigation program have the added responsibility to interact with the ultimate users of the research. This has been effective because the program has attracted many of the most productive and respected researchers and engineers in both universities and the private sector, many being members of the National Academies of Science and Engineering. The stature and wide-ranging involvement of such individuals as consultants to other Government agencies and the private sector firms have provided a direct mechanism for introducing research results into practice.

In a more traditional mode, the earthquake hazard mitigation program distributes all technical reports to the National Technical Information Service, and has established and maintained the National Information Service for Earthquake Engineering at the University of California, Berkeley, and at the California Institute of Technology.

In 1969, an NAS committee, chaired by Dr. George Housner of the California Institute of Technology, conducted a study, "earthquake engineering research."

[Slide shown.]

Dr. HALL. The resulting document provided a complete evaluation of the status of earthquake effects mitigation at that time and made recommendations for future research. And then, in 1982, another committee, again chaired by Dr. Housner, completed a simi-

lar study to assess the progress that has been made since the 1969 report. This report documents the technological and social advancement in all areas of earthquake engineering, identifies needed future research, and recommends appropriate funding levels to continue the progress required to minimize the impact of future earthquakes.

In the engineering directorate, future research activities will emphasize the response of geotechnical materials to dynamic forces, including liquefaction, which I mentioned, large and full-scale testing of numerous types of structures and lifelines to verify and develop new concepts, will look at the inelastic behavior of structures subjected to seismic loads, special instrument arrays in highly seismic areas of the world, the behavior of low-rise structures, and the influence of architectural and urban planning on the vulnerability of structures and communities.

We will continue research to determine the three-dimensional behavior of engineering materials and structures in an earthquake environment. We will continue to study the impacts of earthquakes on social and economic community systems, and develop procedures that will minimize these impacts.

Thank you, Mr. Chairman, for allowing me to summarize the activities of the earthquake programs in the National Science Foundation. Thank you.

[The prepared statement of Dr. Hall follows:]

STATEMENT OF DR. CARL W. HALL, ACTING ASSISTANT DIRECTOR, ENGINEERING,
NATIONAL SCIENCE FOUNDATION (NSF)

MR. CHAIRMEN AND MEMBERS OF THE SUBCOMMITTEES--

SINCE PASSAGE OF THE NATIONAL EARTHQUAKE HAZARDS REDUCTION (NEHR) ACT IN 1977, NSF HAS ACCELERATED RESEARCH IN THIS IMPORTANT AREA. OBLIGATIONS DURING THIS PERIOD HAVE BEEN APPROXIMATELY \$170 MILLION, WITH 70% OF THE EXPENDITURES BEING MADE BY THE ENGINEERING DIRECTORATE (ENG) AND THE REMAINING 30% BY THE DIRECTORATE FOR ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES (AAEO). TODAY I AM PLEASED TO REPORT ON HOW RESEARCH ADVANCEMENTS BEING MADE IN ENGINEERING, ARCHITECTURE, PLANNING, SEISMOLOGY AND SOCIETAL RESPONSE ADDRESS THE EARTHQUAKE PROBLEMS IN THE EASTERN UNITED STATES.

THREE OTHER PRINCIPLE AGENCIES IN ADDITION TO NSF HAVE BEEN INVOLVED IN CARRYING OUT THE PROVISIONS OF THE NEHR ACT, I.E., THE LEAD AGENCY, THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA), THE U.S. GEOLOGICAL SURVEY (USGS), AND THE NATIONAL BUREAU OF STANDARDS (NBS). WE WORK CLOSELY WITH THESE AGENCIES IN ACCOMPLISHING THE OBJECTIVES OF THE ACT.

THE EARTHQUAKE PROBLEM IS TRULY NATIONAL IN SCOPE BECAUSE MOST STATES HAVE SOME DEGREE OF SEISMIC RISK. FURTHER, STUDIES BY THE U.S. GEOLOGICAL SURVEY (USGS) INDICATE THAT THE PROBABILITY OF A LARGE EARTHQUAKE IN CALIFORNIA IS INCREASING EACH YEAR.

ALTHOUGH THE GREATEST SEISMIC HAZARD IS PRESENTLY BELIEVED TO BE ON THE WEST COAST, RECENT CONCERN HAS BEEN EXPRESSED ABOUT POSSIBLE EARTHQUAKES IN THE EASTERN U.S., SIMILAR TO THE 1811-12 NEW MADRID, MISSOURI, (MAGNITUDE 7.8) AND THE 1886 CHARLESTON, SOUTH CAROLINA, (MAGNITUDE 7.0) EARTHQUAKES. SHOULD EARTHQUAKES OCCUR IN A MAJOR METROPOLITAN AREA, EXTENSIVE PROPERTY DAMAGE AND LOSS OF LIFE COULD RESULT, PARTICULARLY WHERE MAN-MADE FACILITIES ARE NOT SEISMICALLY RESISTANT.

MAJOR EASTERN UNITED STATES EARTHQUAKES DIFFER FROM THEIR WESTERN COUNTERPARTS IN SEVERAL IMPORTANT WAYS:

- o ATTENUATION OF GROUND MOTION IN THE RANGE OF DAMAGING WAVE FREQUENCIES IS MUCH LESS IN THE EAST, RESULTING IN DAMAGE AREAS APPROXIMATELY TWENTY TIMES GREATER THAN FOR EARTHQUAKES IN THE WEST OF THE SAME MAGNITUDE;
- o EAST OF THE ROCKY MOUNTAINS, FAULTS ARE OFTEN OBSCURED BY VEGETATION AND THICK SEDIMENTARY COVER AND MOVEMENT ON THESE FAULTS RARELY RESULT IN GROUND BREAKAGE;
- o THE RECURRENCE INTERVAL RATE OF MAJOR EARTHQUAKES IN THE EAST IS ABOUT SIX TO SEVEN TIMES LONGER THAN FOR COMPARABLE EARTHQUAKES IN THE WEST.

THE BURIED FAULTS AND THE LONG TIME-INTERVAL BETWEEN MAJOR EARTHQUAKES IN THE EAST HAVE CONTRIBUTED TO OUR LACK OF KNOWLEDGE OF THE TECTONIC PROCESSES RESPONSIBLE FOR EASTERN U.S. EARTHQUAKES AND TO A GENERAL NONAWARENESS OR NONAPPRECIATION OF THE SEVERITY OF THE EARTHQUAKE HAZARD FOR THAT PART OF THE COUNTRY.

I WILL DISCUSS THE RESEARCH ACTIVITIES WITHIN THE DIVISION OF EARTH SCIENCES (AAEO) AND THE PROBLEM-FOCUSED EARTHQUAKE HAZARD MITIGATION PROGRAM (EHM) WHICH RESIDES IN THE DIVISION OF CIVIL AND ENVIRONMENTAL ENGINEERING (ENG).

IN THE AAEO DIRECTORATE, THE FUNDAMENTAL EARTHQUAKE STUDIES ELEMENT IS SUPPORTED PRIMARILY THROUGH THE SEISMOLOGY PROGRAM OF THE DIVISION OF EARTH SCIENCES. SEISMOLOGY IS THE PRIMARY METHOD OF STUDYING THE STRUCTURE AND PHYSICAL PROPERTIES OF THE EARTH'S INTERIOR AND OF DEFINING THE PLATES MAKING UP THE EARTH'S LITHOSPHERE. AS SUCH, SEISMOLOGY AND OTHER EARTHQUAKE RELATED TOPICS HAVE CONSTITUTED AN IMPORTANT PART OF THE DIVISION'S PROGRAM FOR SOME 20 YEARS. THIS RESEARCH CONSISTS OF DETAILED STUDIES AND MEASUREMENTS DIRECTED AT UNDERSTANDING THE NATURAL PHENOMENA INVOLVED IN AN EARTHQUAKE. THE MAJOR GOAL IS TO PROVIDE THE BASIC SCIENTIFIC FRAMEWORK ON WHICH EMPIRICAL PROGRAMS OF EARTHQUAKE PREDICTION CAN BE BASED.

THE GENERAL OBJECTIVE OF THE EHM PROGRAM IN THE ENGINEERING DIRECTORATE IS TO CONDUCT RESEARCH WHICH WILL RESULT IN IMPROVED DESIGN METHODOLOGIES, WHICH IN TURN WILL LEAD TO MINIMIZATION OF PROPERTY DAMAGE AND WILL HELP TO ELIMINATE LOSS OF LIFE FROM POTENTIALLY DAMAGING EARTHQUAKES. TO ACCOMPLISH THESE OBJECTIVES REQUIRES BROAD PARTICIPATION IN THE RESEARCH PROGRAM BY ARCHITECTS, URBAN PLANNERS, EARTH SCIENTISTS, GEOTECHNICAL ENGINEERS, STRUCTURAL ENGINEERS, AND SOCIAL SCIENTISTS. FOR BUDGET PURPOSES, THE EHM PROGRAM IS DIVIDED INTO THE THREE GENERAL RESEARCH AREAS OF SITING, DESIGN AND SOCIETAL RESPONSE. THE SPECIFIC OBJECTIVES ARE:

- o SITING RESEARCH, WHICH SEEKS TO DETERMINE FROM INSTRUMENTATION AND GEOTECHNICAL DATA THE NATURE OF STRONG GROUND SHAKING DURING EARTHQUAKES, TO DEVELOP ANALYTICAL PROCEDURES TO PREDICT THE SPATIAL AND TEMPORAL DISTRIBUTION OF STRONG GROUND MOTION AT DIFFERENT SITES, TO UNDERSTAND THE DYNAMIC BEHAVIOR OF SOIL AND ROCK SUBJECT TO STRONG SHAKING, THE INTERACTION BETWEEN THE SOIL AND STRUCTURES, AND TO UNDERSTAND THE BEHAVIOR OF THE OCEAN, PARTICULARLY ITS MARGINS, DUE TO UNDERWATER EARTHQUAKES PRODUCING DAMAGING TSUNAMIS.
- o DESIGN RESEARCH, WHICH AIMS TO DEVELOP PROCEDURES FOR PERFORMING DYNAMIC ANALYSES OF PROPOSED OR EXISTING STRUCTURES UNDER EARTHQUAKE LOADINGS, TO DEVELOP AN UNDERSTANDING OF MATERIAL, COMPONENTS, AND STRUCTURAL SYSTEMS SUBJECTED TO DAMAGING DYNAMIC LOADS, AND TO DEVELOP PROCEDURES FOR THE ANALYSIS AND DESIGN OF NONSTRUCTURAL AND ARCHITECTURAL SYSTEMS SUBJECTED TO EARTHQUAKE LOADINGS.
- o SOCIETAL RESPONSE RESEARCH, WHICH STUDIES AND EVALUATES MEASURES THAT CAN BE USED TO MITIGATE SOCIETY'S LOSSES DUE TO EARTHQUAKES, INCLUDING EMERGENCY PREPAREDNESS, LAND USE PLANNING, BUILDING CODES, INSURANCE, AND INFORMATION AND EDUCATION, AS WELL AS OTHER ACTIONS COMMUNITIES CAN TAKE TO WITHSTAND EARTHQUAKES AND OTHER DISASTERS WITH MINIMAL IMPACT ON BOTH LIFE AND PROPERTY.

WITHIN EACH OF THE ABOVE OBJECTIVES IS RESEARCH RELATED TO

"LIFELINES", FACILITIES THAT ARE ESSENTIAL TO ORDERLY RECOVERY FOLLOWING AN EARTHQUAKE. LIFELINES INCLUDE COMMUNICATIONS, UTILITIES (WATER, SEWER, GAS, ETC.) AND TRANSPORTATION FACILITIES (HIGHWAYS, RAILWAYS, AIRPORTS, BRIDGES, PORTS, ETC.).

THE PLATE TECTONIC HYPOTHESIS HAS PROVIDED A GOOD UNDERSTANDING FOR A NUMBER OF THE WORLD'S MOST ACTIVE EARTHQUAKE BELTS WHICH ARE LOCATED ALONG PLATE BOUNDARIES. NEVERTHELESS, THERE HAS BEEN RELATIVELY LITTLE WORK DONE ON EARTHQUAKES WHICH OCCUR INSIDE OF THE LARGE LITHOSPHERIC PLATES THAT MAKE UP THE SURFACE OF THE EARTH. THE EASTERN U.S. LIES WITHIN THE NORTH AMERICAN PLATE. ALTHOUGH INTRAPLATE EARTHQUAKES ACCOUNT FOR ONLY A FEW PERCENT OF THE WORLD'S EARTHQUAKES, A NUMBER OF LARGE AND DAMAGING SHOCKS HAVE OCCURRED WITHIN VARIOUS PLATES INCLUDING THE EARTHQUAKES NEAR NEW MADRID, MISSOURI IN 1811-1812; CHARLESTON, SOUTH CAROLINA IN 1886; NEAR CAPE ANN, MASSACHUSETTS IN 1755; OFF THE GRAND BANKS OF NEWFOUNDLAND IN 1919 AND A NUMBER OF SHOCKS IN THE ST. LAWRENCE VALLEY THROUGHOUT THE LAST 400 YEARS. THUS, IT IS CLEAR THAT THE INTERIORS OF PLATES ARE NOT TOTALLY FREE OF LARGE AND DAMAGING EARTHQUAKES.

SEVERAL OF THE LARGE HISTORIC SHOCKS IN EASTERN AND CENTRAL NORTH AMERICA ARE LOCATED NEAR WHAT ARE NOW POPULATED REGIONS. ALSO, MOST OF THE NUCLEAR POWER PLANTS IN THE UNITED STATES AND CANADA ARE SITUATED IN THE EASTERN HALF OF THOSE COUNTRIES. IT IS CRUCIAL TO KNOW, FOR EXAMPLE, WHETHER LARGE SHOCKS LIKE THAT NEAR CHARLESTON IN 1886 CAN OCCUR AT RANDOM ANYWHERE WITHIN THE NORTH AMERICAN PLATE OR WHETHER SUCH SHOCKS OCCUR ALONG SPECIFIC TECTONIC FEATURES FOR WHICH THE SEISMIC RISK IS MUCH HIGHER THAN OTHER PARTS OF THE PLATE.

UNTIL ABOUT 1970 VERY FEW SEISMIC INSTRUMENTS HAD BEEN INSTALLED IN THE UNITED STATES EAST OF THE ROCKY MOUNTAINS. HENCE, IT WAS NOT POSSIBLE TO ASSOCIATE THE LOCATIONS OF PARTICULAR EARTHQUAKES WITH FAULTS AND OTHER TECTONIC FEATURES. RECENTLY IN A COOPERATIVE MODE WITH OTHER AGENCIES, A NUMBER OF NEW SEISMOGRAPH STATIONS HAVE BEEN INSTALLED IN THE NORTHEASTERN UNITED STATES, IN THE CENTRAL MISSISSIPPI VALLEY AND SOUTH CAROLINA. AS A RESULT, IT IS NOW POSSIBLE TO LOCATE EARTHQUAKES WITHIN THE ABOVE MENTIONED NETWORKS WITH A PRECISION OF ABOUT 2 KM AND TO DETECT SHOCKS AS SMALL AS RICHTER MAGNITUDE 2. THIS HAS PROVIDED NEARLY A HUNDRED-FOLD INCREASE IN THE NUMBER OF EVENTS DETECTED OVER THOSE REGISTERED BY THE OLDER SEISMOGRAPH STATIONS. EARTHQUAKES WITHIN EASTERN NORTH AMERICA HAVE BEEN A LIVELY TOPIC AT A NUMBER OF PROFESSIONAL MEETINGS FOR THE PAST FEW YEARS.

THE MOST SEISMICALLY ACTIVE REGION IN THE UNITED STATES EAST OF THE ROCKY MOUNTAINS IS LOCATED ALONG THE MISSISSIPPI VALLEY IN SOUTHEASTERN MISSOURI. THIS AREA WAS THE SITE OF THE GREAT EARTHQUAKES OF 1811-1812. RESULTS FROM A NEW SEISMOGRAPH NETWORK SHOW THAT EARTHQUAKES ARE OCCURRING ALONG NORTHEASTERLY AND NORTHWESTERLY TRENDING FAULTS IN THIS AREA. RECENT WORK ON TRENCHING HAS SHOWN A REPEAT TIME OF ABOUT 700 YEARS FOR LARGE EARTHQUAKES IN THE AREA NEAR NEW MADRID. THIS IS THE FIRST TIME IN WHICH A RELIABLE REPEAT TIME HAS BEEN ESTABLISHED FOR AN AREA EAST OF THE ROCKY MOUNTAINS IN THE UNITED STATES.

AS AN EXAMPLE OF WHAT IS BEING DONE TO UNDERSTAND THESE LARGE HISTORICAL SHOCKS IN THE EASTERN U.S., I WOULD LIKE TO BRIEFLY

DESCRIBE TO YOU THE RESULTS OF A RESEARCH PROJECT SUPPORTED BY NSF WHICH MAY HAVE RELEVANCE TO THE QUESTION OF THE ULTIMATE CAUSE OF THE 1886 CHARLESTON EARTHQUAKE. THE PROJECT IS KNOWN AS COCORP (CONSORTIUM FOR CONTINENTAL REFLECTION PROFILING) AND CONSISTS OF A CONSORTIUM OF FIVE UNIVERSITIES: CORNELL, RICE, DARTMOUTH, WISCONSIN AND PRINCETON, WITH CORNELL AS THE OPERATING INSTITUTION. THE PROJECT USES SEISMIC REFLECTION PROFILING TECHNIQUES ADAPTED FROM THE OIL INDUSTRY TO STUDY THE DEEP STRUCTURE OF THE EARTH'S CRUST AND UPPER MANTLE. SUCH STRUCTURE IS VIRTUALLY UNKNOWN AT DEPTHS BELOW A FEW KILOMETERS AND CONTINUOUS SEISMIC REFLECTION PROFILING GIVES THE HIGHEST RESOLUTION OF ANY GEOPHYSICAL TECHNIQUE FOR STUDYING ITS DETAIL.

IN SEVERAL RECENT STUDIES COCORP HAS OBTAINED REFLECTION PROFILES IN THE SOUTHERN APPALACHIANS AND THE NEW ENGLAND APPALACHIANS. THE RESULTS HAVE VERY IMPORTANT IMPLICATIONS FOR APPALACHIAN GEOLOGY, THE PROCESS OF CONTINENTAL GROWTH, AND FOR A POSSIBLE MECHANISM FOR LARGE EARTHQUAKES IN THE EASTERN U.S. IN PARTICULAR, PROFILING IN GEORGIA, NORTH CAROLINA, AND TENNESSEE INDICATES THAT A THIN SHEET OF OLDER CRYSTALLINE ROCKS HAS BEEN THRUST GREAT DISTANCES OVER A LAYER OF YOUNGER SEDIMENTARY ROCKS WHICH FORMED THE ANCIENT CONTINENTAL MARGIN OF THE LAND MASS THAT WAS TO BECOME NORTH AMERICA. THE OVERLYING CRYSTALLINE ROCKS SEEM TO HAVE BEEN EMPLACED ALONG A MAJOR SUBHORIZONTAL THRUST FAULT (A HORIZONTAL FAULT BELOW THE SURFACE). OVERTHRUSTING MAY HAVE BEEN AS GREAT AS 260 KM HORIZONTALLY, AND WAS PERHAPS CONSIDERABLY MORE.

THE RESULTS FROM THE NEW ENGLAND PROFILE INDICATE THAT THE SAME KIND OF "THIN-SKINNED" THRUSTING HAS TAKEN PLACE. THE DATA SUPPORT THE VIEW THAT LARGE-SCALE, THIN, CRYSTALLINE THRUST SHEETS MAY BE SIGNIFICANT FEATURES OF IN MANY PARTS OF THE WORLD.

NO GEOLOGIC STRUCTURE OR FEATURE HAS BEEN IDENTIFIED UNEQUIVOCALLY AS THE SOURCE OF THE 1886 CHARLESTON EARTHQUAKE. PRESENT DAY INSTRUMENTALLY LOCATED SEISMICITY NEAR CHARLESTON DEFINES STEEPLY DIPPING, NEAR VERTICAL ZONES OF ACTIVITY WHICH MAY WELL BE THE FAULTS ALONG WHICH THE ACTUAL 1886 SHOCK OCCURRED. HOWEVER, THE POSSIBILITY EXISTS THAT VERY SLOW MOVEMENT AT DEPTH ALONG THE MAJOR SHALLOW THRUST SHEET IDENTIFIED BY COCORP COULD BE A DRIVING MECHANISM FOR THE OBSERVED EARTHQUAKE ACTIVITY ALONG STEEPLY DIPPING PLANES SHALLOWER IN THE CRUST.

IF THIS MAJOR SHALLOW THRUST SHEET IS A PERVASIVE FEATURE ALL ALONG THE EAST COAST OF THE U.S., AND THE ABOVE HYPOTHESIS IS CORRECT, A "CHARLESTON-LIKE" EARTHQUAKE COULD OCCUR ELSEWHERE ON THE EASTERN SEABOARD OF THE UNITED STATES.

I SHOULD EMPHASIZE THAT THE CAUSE OF THE CHARLESTON EARTHQUAKE IS A SUBJECT OF CONTINUING SCIENTIFIC CONTROVERSY AND MUCH MORE WORK NEEDS TO BE DONE BEFORE WE CAN BE CERTAIN THAT THE ABOVE INTERPRETATION IS THE CORRECT ONE.

A RE-OCCURRENCE OF THESE LARGE EARTHQUAKES IN THE EASTERN U.S. COULD CAUSE SEVERE DAMAGE TO PROPERTY AND LOSS OF LIFE. THE ENERGY ABSORPTION (ATTENUATION) OF GEOLOGIC MATERIALS IN THE EAST IS MUCH LESS THAN IN CALIFORNIA,--RESULTING IN A MUCH LARGER AREA BEING IMPACTED BY THE EARTHQUAKE. FOR EXAMPLE, THE NEW MADRID EARTHQUAKES WERE FELT IN BOSTON.

THE 1976 TANGSHAN EARTHQUAKE, IN THE PEOPLES REPUBLIC OF CHINA (PRC) WAS ONE OF THE MOST DEVASTATING IN HISTORY. THE INDUSTRIAL CITY OF TANGSHAN LIES WITHIN A TECTONIC PLATE SIMILAR TO THE EASTERN U.S. WITHOUT WARNING, THE MAGNITUDE 7.9 EARTHQUAKE "LEVELED" MOST OF THE CITY HAVING A POPULATION OF ONE MILLION, WITH FATALITIES ESTIMATED BETWEEN 230,000 TO 750,000 PEOPLE. UNREINFORCED MASONRY STRUCTURES, WHICH ARE VERY SUSCEPTIBLE TO EARTHQUAKE DAMAGE, COLLAPSED UNDER THE STRONG GROUND MOTIONS--KILLING MANY PEOPLE. (DAMAGE TO SUCH STRUCTURES IN THE MAY 1983 COALINGA, CALIFORNIA EARTHQUAKE WAS EXTENSIVE). LOSS OF STRENGTH OF THE SATURATED SUPPORTING SOIL, I.E. LIQUEFACTION, CAN ALSO PRODUCE SEVERE PROBLEMS. THIS TYPE OF STRUCTURE AND SOIL CONDITION IS PREVALENT IN THE EASTERN U.S. ALSO, IT HAS BEEN FOUND THAT THE ATTENUATION CHARACTERISTICS OF THE ADIRONDACK REGION IS SIMILAR TO THAT IN TANGSHAN.

THE RESEARCH CONDUCTED BY EHM GRANTEES IS GENERALLY APPLICABLE IN ALL REGIONS OF THE U.S. ACTIVE RESEARCH AWARDS EXIST AT APPROXIMATELY 65 DIFFERENT ORGANIZATIONS DISTRIBUTED IN THE APPROXIMATE MANNER; 1/3 IN CALIFORNIA, 1/3 IN WESTERN STATES EXCLUDING CALIFORNIA, AND 1/3 TO STATES EAST OF THE MISSISSIPPI RIVER. THIS BROAD DISTRIBUTION OF RESEARCH ACTIVITIES IS ENTIRELY APPROPRIATE BECAUSE GRADUATES OF UNIVERSITIES TEND TO WORK IN ALL PARTS OF THE COUNTRY (AND THE WORLD) AND MUST BE FAMILIAR WITH ASEISMIC DESIGN PROCEDURES.

AN IMPORTANT ELEMENT OF THE NSF RESEARCH PROGRAM IS DEALING WITH EXISTING HAZARDOUS STRUCTURES, INCLUDING LIFELINES. FREQUENT EARTHQUAKES IN CALIFORNIA HAVE KEPT STATE AND LOCAL GOVERNMENT OFFICIALS SENSITIZED TO THE EARTHQUAKE RISKS, AND, THEREFORE, NEW STRUCTURES ARE DESIGNED WITH ADVANCED SEISMIC DESIGN PROCEDURES. HOWEVER, BECAUSE OF RELATIVELY INFREQUENT LARGE EARTHQUAKES IN THE EASTERN U.S., OFFICIALS IN THESE AREAS UNTIL RECENTLY HAVE TENDED TO OVERLOOK EARTHQUAKE CONSIDERATIONS. THUS, THE RE-OCCURRENCE OF A LARGE EARTHQUAKE IN THE EAST COULD CAUSE WIDESPREAD PROPERTY DAMAGE AND LOSS OF LIFE.

RESEARCH IS BEING CONDUCTED TO FIND COST-EFFECTIVE METHODS TO UPGRADE EXISTING STRUCTURES. STANFORD UNIVERSITY IS CONDUCTING A STUDY OF THE BOSTON AREA TO DETERMINE THE IMPACT OF REGULATIONS ON UPGRADING HAZARDOUS BUILDINGS. GEORGIA INSTITUTE OF TECHNOLOGY IS ASSESSING EARTHQUAKE HAZARDS IN EXISTING BUILDINGS IN 5 SOUTHEASTERN CITIES, I.E., MEMPHIS, TENN., ATLANTA, GA., ASHVILLE, N.C., HUNTSVILLE, ALA., AND CHARLESTON, S.C. A PRIVATE SECTOR FIRM, EQE, INC., IS DEVELOPING A METHOD TO ESTIMATE EARTHQUAKE DAMAGE IN HIGH TECHNOLOGY INDUSTRIES AND IS USING THE ELECTRONICS INDUSTRY IN BOSTON AS THE BASE. CORNELL UNIVERSITY IS DEVELOPING TECHNIQUES TO ESTIMATE BUILDING STOCK AT RISK, PARTICULARLY IN OLDER CITIES. THE ARCHITECTURAL RESEARCH CENTERS CONSORTIUM, INC. IS CONDUCTING A STUDY ON PRESERVATION OF HISTORIC STRUCTURES SUBJECTED TO EARTHQUAKES AND OTHER NATURAL HAZARDS. NSF RECENTLY JOINED WITH SEVERAL OTHER AGENCIES TO FUND A WORKSHOP IN CHARLESTON, S.C. TO MAKE LOCAL AND STATE OFFICIALS AWARE OF POTENTIAL EARTHQUAKE PROBLEMS IN THEIR AREA.

OTHER EXAMPLES OF ACTIVITIES WITHIN NSF THAT ARE SPECIFICALLY RELATED TO EARTHQUAKE PROBLEMS IN THE EAST FOLLOW. NSF HAS FUNDED THE EARTHQUAKE ENGINEERING RESEARCH INSTITUTE (EERI) TO CONDUCT SEMINARS IN ALL AREAS OF THE COUNTRY TO FAMILIARIZE

ENGINEERS WITH ASEISMIC DESIGN PRINCIPLES. RECENTLY, AN AWARD WAS MADE TO SUNY-BUFFALO TO COMPLETE A 12 X 12 FOOT BIAXIAL, 5-DEGREE OF FREEDOM EARTHQUAKE SIMULATION FACILITY (SHAKE TABLE), WHICH IS THE MOST VERSATILE SIMULATOR IN NORTH AMERICA. SUNY-BINGHAMTON HAS INSTALLED AND MAINTAINS A STRONG-MOTION INSTRUMENTATION ARRAY IN THE STATE OF NEW YORK. DR. FRANCIS WU, THE PRINCIPAL INVESTIGATOR, IS ALSO COOPERATING WITH SCIENTISTS AND ENGINEERS IN THE TANGSHAN AREA OF THE PRC IN AN ATTEMPT TO UNDERSTAND EARTHQUAKE PROBLEMS IN THE U.S.

IN A COOPERATIVE PROJECT WITH NBS AND THE APPLIED TECHNOLOGY COUNCIL (ATC), NSF PROVIDED ORIGINAL FUNDING IN THE MID-1970'S TO DEVELOP NEW SEISMIC DESIGN PROVISIONS FOR BUILDING CODES. WITH FUNDING BY FEMA, THE BUILDING SEISMIC SAFETY COUNCIL (BSSC) IS NOW EVALUATING THESE PROVISIONS FOR MANY LARGE METROPOLITAN AREAS THROUGHOUT THE U.S. IN CONJUNCTION WITH THESE ACTIVITIES THE NATIONAL RESEARCH COUNCIL'S COMMITTEE ON EARTHQUAKE ENGINEERING HAS MADE ITS HIGHEST PRIORITY TASK AN EVALUATION OF THE NATIONAL STRONG MOTION INSTRUMENTATION PROGRAM FOR THE ENTIRE U.S.

FOR A NUMBER OF YEARS NSF HAS FUNDED A SPECIFIC TYPE OF RESEARCH TO MAKE STRUCTURES SEISMICALLY RESISTANT, NAMELY BASE ISOLATION. THIS CONCEPT HAS RECENTLY BEEN INCORPORATED INTO THE DESIGN AND CONSTRUCTION OF THE FOOTHILL COMMUNITIES LAW AND JUSTICE CENTER IN SAN BERNARDINO COUNTY, CALIFORNIA. THE 1971 SAN FERNANDO EARTHQUAKE EMPHASIZED THE IMPORTANCE OF SEISMIC DESIGN FOR LIFELINES. EXTENSIVE DAMAGE RESULTED TO UNDERGROUND WATER AND SEWER LINES, GAS PIPELINES, ELECTRICAL SUBSTATION EQUIPMENT, COMMUNICATIONS SYSTEMS, AND TRANSPORTATION FACILITIES. SEISMIC DESIGN CRITERIA HAD BEEN ABSENT IN SUCH FACILITIES. BECAUSE OF THE GREAT LENGTH OF SUCH FACILITIES GROUND MOTION CRITERIA APPLICABLE TO CONVENTIONAL STRUCTURES ARE NOT SUITABLE. RESEARCH UTILIZING SEISMIC RISK ANALYSIS OF NETWORK SYSTEMS AND ECONOMIC PRINCIPLES HAS ENLIGHTENED US ON HOW SUCH FACILITIES RESPOND IN AN EARTHQUAKE ENVIRONMENT. DESPITE SIGNIFICANT ADVANCES IN THE LAST DECADE, THE STATE-OF-THE-ART IS STILL LAGGING WELL BEHIND OUR UNDERSTANDING OF THE RESPONSE OF CONVENTIONAL STRUCTURES. THERE REMAINS AN URGENT NEED TO EXPAND THE EXPERIMENTAL DATA BASE FOR LIFELINE SYSTEMS.

THE CRITICAL NATURE OF LIFELINE SYSTEMS HAS GENERATED A NUMBER OF FORMAL GROUPS. THE AMERICAN SOCIETY OF CIVIL ENGINEERS HAS AN ACTIVE TECHNICAL COUNCIL ON LIFELINE EARTHQUAKE ENGINEERING (TCLEE). THE INTERAGENCY COMMITTEE ON SEISMIC SAFETY IN CONSTRUCTION (ICSSC) HAS FORMED A LIFELINES SUBCOMMITTEE. THIS SUBCOMMITTEE HELD A WORKSHOP IN WASHINGTON, D.C. ON MARCH 20, WHICH INCLUDED PARTICIPATION BY TCLEE, BELL LABORATORIES AND THE ELECTRIC RESEARCH POWER INSTITUTE (EPRI). A JOINT MEETING WITH JAPANESE COUNTERPARTS WAS HELD ON MAY 14. A WORKSHOP TO DEFINE RESEARCH NEEDS IN THIS IMPORTANT AREA IS TO BE HELD IN CALIFORNIA ON MAY 29-31.

NSF HAS TURNED ITS ATTENTION, FOR EXAMPLE, TO SOCIOECONOMIC ISSUES IN THE NEW MADRID FAULT AREA, IN PART TO COMPLEMENT RESEARCH, PREPAREDNESS, AND MITIGATION PROGRAMS UNDERTAKEN BY USGS AND FEMA. WITH NSF SUPPORT, THOMAS DRABEK AND HIS COLLEAGUES AT THE UNIVERSITY OF DENVER RECENTLY COMPLETED A STUDY ON EARTHQUAKE HAZARD MITIGATION EFFORTS IN MISSOURI, WHICH IS PART OF THE NEW MADRID REGION, AND THE STATE OF WASHINGTON. THIS

STUDY OFFERS USEFUL INSIGHTS REGARDING THE DIFFICULTIES OF A NONTECHNICAL NATURE THAT CAN EMERGE IN STATES THAT HAVE FLEDGLING MITIGATION PROGRAMS.

ALVIN MUSHKATEL AND JOANNE NIGG OF ARIZONA STATE UNIVERSITY HAVE UNDERTAKEN A MAJOR EARTHQUAKE STUDY IN SEVERAL CENTRAL STATES, INCLUDING TENNESSEE, ARKANSAS, MISSOURI, AND ILLINOIS. THE STUDY IS DETERMINING THE MAJOR INCENTIVES AND DISINCENTIVES FOR DEVELOPING AND IMPLEMENTING EARTHQUAKE HAZARD MITIGATION POLICY IN THE AREA, THE PUBLIC'S RECEPTIVITY TO SEISMIC SAFETY INITIATIVES AND PLANNING PROGRAMS, AND THE STATUS OF DISASTER PREPAREDNESS AND PLANNING EFFORTS. FEMA IS COOPERATING WITH THE RESEARCH TEAM AND IS PROVIDING ADDITIONAL FUNDING SO THAT SPECIAL ATTENTION CAN BE GIVEN TO THE EVALUATION OF SELECTED HAZARD INFORMATION DISSEMINATION INITIATIVES IN THE REGION.

BECAUSE OF THE URGENCY IN MAKING PREPARATIONS FOR A MAJOR EARTHQUAKE, WE HAVE NOT BEEN CONTENT WITH ONLY REPORTING RESEARCH RESULTS IN TECHNICAL JOURNALS, BUT HAVE ATTEMPTED TO ACCELERATE THE UTILIZATION OF FINDINGS. THIS HAS REQUIRED EXTENSIVE INTERACTION WITH OTHER FEDERAL AGENCIES, AND WHEN APPROPRIATE, WITH STATE AND LOCAL OFFICIALS. FOR EXAMPLE, NSF CO-SPONSORED THE INTERNATIONAL EARTHQUAKE CONFERENCE THAT WAS HELD AT THE UNIVERSITY OF SOUTHERN CALIFORNIA ON FEBRUARY 7-11, 1983. SUPPORT FOR THE CONFERENCE WAS ALSO PROVIDED BY THE AGENCY FOR INTERNATIONAL DEVELOPMENT (AID), THE U.S. GEOLOGICAL SURVEY (USGS), AND THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA). THE CONFERENCE WAS DESIGNED FOR POLICY MAKERS AND ADMINISTRATORS IN LOCAL GOVERNMENTS FACING EARTHQUAKE RISKS. OVER 200 REPRESENTATIVES FROM SEVERAL SEISMIC-THREATENED COUNTRIES, INCLUDING THE PHILIPPINES, ITALY, JAPAN, MEXICO, AND PERU ATTENDED THE CONFERENCE AND SHARED THEIR EXPERIENCE IN ATTEMPTING TO UNDERSTAND, MITIGATE, AND PREPARE FOR DESTRUCTIVE EARTHQUAKES. THE MULTI-NATIONAL PRESENTATIONS AT THE CONFERENCE WILL RESULT IN THE PUBLICATION OF RECOMMENDATIONS FOR REDUCING EARTHQUAKE HAZARDS IN VULNERABLE URBAN AREAS THROUGHOUT THE WORLD.

THE RESEARCHERS PARTICIPATING IN THE EHM PROGRAM HAVE THE ADDED RESPONSIBILITY TO INTERACT WITH THE ULTIMATE USERS OF THE RESEARCH. THIS HAS BEEN EFFECTIVE BECAUSE THE EHM PROGRAM HAS ATTRACTED MANY OF THE MOST PRODUCTIVE AND RESPECTED RESEARCHERS AND ENGINEERS IN BOTH THE UNIVERSITIES AND THE PRIVATE SECTOR, MANY BEING MEMBERS OF THE NATIONAL ACADEMIES OF SCIENCE AND ENGINEERING. THE STATURE AND WIDE-RANGING INVOLVEMENT OF SUCH INDIVIDUALS AS CONSULTANTS TO OTHER GOVERNMENT AGENCIES AND PRIVATE SECTOR FIRMS HAVE PROVIDED A DIRECT MECHANISM FOR INTRODUCING RESEARCH RESULTS INTO PRACTICE.

IN A MORE TRADITIONAL MODE, THE EHM PROGRAM DISTRIBUTES ALL TECHNICAL REPORTS THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS) AND HAS ESTABLISHED AND MAINTAINED THE NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING (NISEE) AT THE UNIVERSITY OF CALIFORNIA, BERKELEY, AND AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY. THESE FACILITIES ATTEMPT TO RETAIN ALL PERTINENT INFORMATION ON EARTHQUAKE ENGINEERING (INCLUDING DOCUMENTS FROM FOREIGN COUNTRIES) IN THE FORM OF TECHNICAL PUBLICATIONS, COMPUTER CODES, AND JOURNAL ABSTRACTS. SIMILAR CATALOGING OF PERTINENT INFORMATION ON THE SOCIAL SCIENCE ASPECTS IS MAINTAINED IN THE NATIONAL HAZARDS RESEARCH AND APPLICATION

INFORMATION CENTER AT THE UNIVERSITY OF COLORADO IN BOULDER. WS ALSO HAVE SUPPORTED NUMEROUS SEMINARS, WORKSHOPS AND CONFERENCES TO INTRODUCE THE USERS TO THE LATEST ADVANCEMENTS IN TECHNOLOGY.

COORDINATION WITH OTHER AGENCIES IS ACCOMPLISHED BOTH ON A FORMAL AND INFORMAL BASIS THROUGH NUMEROUS MECHANISMS. A REVIEW GROUP, CONSISTING OF POLICY-LEVEL ADMINISTRATORS FROM NSF, U.S. GEOLOGICAL SURVEY, FEDERAL EMERGENCY MANAGEMENT AGENCY AND NATIONAL BUREAU OF STANDARDS, WAS RECENTLY ESTABLISHED FOR THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM (NEHRP), WHICH WILL PROVIDE FORMAL COORDINATION AMONG THE INVOLVED AGENCIES ON A PERIODIC BASIS. NSF ALSO WORKS CLOSELY WITH THE LEAD AGENCY (FEMA) IN PREPARING AN ANNUAL REPORT TO CONGRESS AND THE FIVE-YEAR PLAN FOR THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM.

IN 1969 AN NAS COMMITTEE, CHAIRED BY DR. GEORGE HOUSNER OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY, CONDUCTED A STUDY "EARTHQUAKE ENGINEERING RESEARCH." THE RESULTING DOCUMENT PROVIDED A COMPLETE EVALUATION OF THE STATUS OF EARTHQUAKE EFFECTS MITIGATION CAPABILITY AT THAT TIME AND MADE RECOMMENDATIONS FOR FUTURE RESEARCH. ANOTHER COMMITTEE, AGAIN CHAIRED BY DR. HOUSNER, COMPLETED A SIMILAR STUDY TO ASSESS THE PROGRESS THAT HAS BEEN MADE SINCE THE 1969 REPORT. THIS REPORT DOCUMENTS THE TECHNOLOGICAL AND SOCIAL ADVANCEMENTS IN ALL AREAS OF EARTHQUAKE ENGINEERING, IDENTIFIES NEEDED FUTURE RESEARCH, AND RECOMMENDS APPROPRIATE FUNDING LEVELS TO CONTINUE THE PROGRESS REQUIRED TO MINIMIZE THE IMPACT OF FUTURE EARTHQUAKES.

ALTHOUGH CONSIDERABLE PROGRESS HAS BEEN MADE IN THE LAST EIGHT YEARS IN UNDERSTANDING EASTERN EARTHQUAKES, OUR KNOWLEDGE OF INTRAPLATE SHOCKS IS ONLY AVAILABLE IN A FEW AREAS. IT APPEARS POSSIBLE TO MAKE GREAT PROGRESS DURING THE NEXT 5 TO 10 YEARS IN CORRELATING THE OCCURRENCE OF EARTHQUAKES WITH SPECIFIC FAULTS AND OTHER MAJOR GEOLOGICAL FEATURES. SEVERAL ZONES OF HISTORIC SEISMIC ACTIVITY IN EASTERN NORTH AMERICA OCCUR NEAR CONTINENTAL MARGINS. THIS INCLUDES THE EARTHQUAKES OFF CAPE ANN MASSACHUSETTS IN THE 17TH AND 18TH CENTURIES AND NEAR CHARLESTON IN 1886. IT WOULD BE VERY INTERESTING TO FIND OUT IF THESE SHOCKS LEFT GEOLOGICAL EXPRESSIONS WHICH CAN BE DETECTED BY MARINE TECHNIQUES ON THE CONTINENTAL SHELF. AN ANALYSIS OF A PROMINENT SERIES OF EARTHQUAKES ABOUT A YEAR AGO NEAR BERMUDA SHOULD PROVIDE IMPORTANT EVIDENCE ON THE DIRECTIONS AND STATE OF STRESS IN THE WESTERN ATLANTIC.

STATISTICAL METHODS HAVE BEEN DERIVED FOR ESTIMATING THE RECURRENCE TIMES OF A GIVEN LEVEL OF SHAKING AT A GIVEN LOCATION. WITHIN THE NEXT TEN YEARS THESE TECHNIQUES COUPLED WITH THE NEWLY-REANALYZED DATA FOR HISTORIC SHOCKS SHOULD PROVIDE RELIABLE ESTIMATES OF THE LONG-TERM HAZARD FROM EASTERN EARTHQUAKES. THIS IS VITAL IN THE SAFE SITING OF NUCLEAR POWER PLANTS AND OTHER CRITICAL STRUCTURES.

IN THE ENGINEERING DIRECTORATE, FUTURE RESEARCH ACTIVITIES WILL EMPHASIZE THE RESPONSE OF GEOTECHNICAL MATERIALS TO DYNAMIC FORCES INCLUDING LIQUEFACTION, LARGE-AND FULL-SCALE TESTING OF NUMEROUS TYPES OF STRUCTURES AND LIFELINES TO VERIFY AND DEVELOP NEW CONCEPTS, THE INELASTIC BEHAVIOR OF STRUCTURES SUBJECTED TO SEISMIC LOADS, SPECIAL INSTRUMENT ARRAYS IN HIGHLY SEISMIC AREAS

OF THE WORLD, THE BEHAVIOR OF "LOW-RISE" STRUCTURES, AND THE INFLUENCE OF ARCHITECTURAL AND URBAN PLANNING ON THE VULNERABILITY OF STRUCTURES AND COMMUNITIES. WE WILL CONTINUE RESEARCH TO DETERMINE THE 3-DIMENSIONAL BEHAVIOR OF ENGINEERING MATERIALS AND STRUCTURES IN AN EARTHQUAKE ENVIRONMENT. WE WILL CONTINUE TO STUDY THE IMPACTS OF EARTHQUAKES ON SOCIAL AND ECONOMIC COMMUNITY SYSTEMS AND DEVELOP PROCEDURES THAT WILL MINIMIZE THESE IMPACTS.

THANK YOU MR. CHAIRMEN FOR ALLOWING ME TO SUMMARIZE THE ACTIVITIES OF THE EARTHQUAKE HAZARD MITIGATION PROGRAM IN THE NATIONAL SCIENCE FOUNDATION. SIGNIFICANT PROGRESS CONTINUES TO BE MADE IN A VARIETY OF SCIENTIFIC, ENGINEERING AND SOCIAL AREAS AND THE RESEARCH EFFORTS THAT WE ARE SUPPORTING ARE DIRECTLY AFFECTING DESIGN AND MITIGATION PROCEDURES IN ALL PARTS OF THE U.S.

I WILL BE HAPPY TO ANSWER ANY QUESTIONS THAT YOU OR MEMBERS OF THE SUBCOMMITTEE MAY HAVE.

Mr. GORE. Thank you very much.

With your indulgence, we're going to have to have a recess for 5 minutes. It won't be as long as the last one, and I will be right back to start the hearing. I apologize.

[Recess.]

Mr. GORE. The subcommittees will come back to order. Again, I apologize for the delay, and we will proceed with your testimony.

Dr. LYONS. Thank you, Mr. Chairman. I'm John Lyons, director of the engineering laboratory at the National Bureau of Standards.

The NBS Program in earthquake hazard mitigation is part of our work on structural engineering, which is the same place where we do our investigations of structural failures, in which the chairman has some interest.

Mr. GORE. Yes.

Dr. LYONS. And that, in turn, is part of our center for building research, of which Dr. Wright is the director.

Mr. GORE. I never thought we'd be seeing so much of each other this year.

Dr. LYONS. Our program in the earthquake area relates to performance criteria for building codes and standards and for measurement technology necessary for earthquake-resistant construction. We work in two parts of the program. One with safe and economic new construction; and second, the assessment and means to mitigate hazards in existing structures.

My full statement contains the details of our entire program on earthquakes, the entire program being not very large. What I would like to do just in a couple of minutes is focus on the Central and Eastern U.S. problem.

First, let me say that there are no detailed surveys of building practice or of building codes and standards for that region with regard to earthquake provisions. But in general, we think intuitively it is fair to say that seismic design is simply not practiced in those parts of the country. And let me then give you some anecdotal information which causes us to draw that conclusion.

First of all, the technical council on lifeline earthquake engineering of the American Society of Civil Engineers has looked at this

problem, and their look suggests that little consideration is given to seismic issues in this region of the country.

Second, the chairman of the Committee on Electric Power and Communication Lifelines has said that consideration is rarely given to seismic design for power distribution and transmission in the Midwest.

Now let me briefly talk about the Building Seismic Safety Council and its activities. There are design trials in New York City, Chicago, St. Louis, Memphis and Charleston, and the experience of those trials suggests that local codes do not routinely include seismic-resistant provisions. So that—those are some of the reasons why we say to you that there is not much in the way of engineering practice in that part of the country that relates to designing in seismic resistance.

Now the Bureau's effort does apply to the earthquake problem with the entire country. We do some research that is necessary to devise and improve criteria for seismic resistance. We help develop seismic design standards for Federal construction. Indeed, we chair the Interagency Council. And we encourage use of these design standards by State and local jurisdictions.

The recommendations from the Building Seismic Safety Council, which will come from this set of design competitions, if you will, will be in next week. That is, the results of the designs will be in next week. Balloting by the membership will proceed in July. And one can expect that in 1985 the results of this activity by BSSC should be available, should be public and should be presented to the model building code groups.

Now the way model code groups proceed is they will have to deliberate and argue as to whether or not some of these recommendations should be incorporated in the model building codes. Once that process has been completed, and that tends to—they're on a 3-year cycle—we then have the problem of whether the model codes will be adopted by the local jurisdictions. In some cases, they might be adopted by States, and in some States they are then minimum requirements on local jurisdictions; in other cases, it's up to every local governmental body as to whether to adopt these things into local ordinance. So what I am describing is, I think, a very long process before our building codes in the Midwest and East will be upgraded in terms of seismic provisions.

Now, beside the fact that the process itself is inherently slow, there is also going to be the argument at the local level that occurs on every such issue. For example, a change in the fire codes always stirs up an argument between those who are concerned with public safety and those who worry about the increase in cost.

Now, in large structures, the increases in cost have been estimated for seismic provisions in the Midwest and East to be of the order of a few percent. And, of course, the benefit from those increases in cost is reduced damage in the catastrophe that we have heard about today and which will occur some day.

I should point out that there's a side benefit to designing in seismic resistance, and that is that one gets resistance to severe winds at the same time. Resistance to explosions, accidental or otherwise, is also provided by these same provisions. So it's not really fair to

make a cost-benefit analysis and just think about the rare earthquake.

What I've just said about a few percent increase in cost was for large engineered, specially-designed structures. For one- and two-family homes—Dick and I have been talking the last couple of days about what it really takes to provide seismic resistance in small structures, particularly woodframe buildings, and we estimate a few hundred dollars. It is mostly a matter of paying attention and making sure that you use sufficient nails, that you tie things down—which you would need also for wind resistance—and a little reinforcing here and there.

So I thought you'd be most interested in those conclusions about what's the situation with regard to codes and standards, and I will let the technical program of the Bureau appear in the record.

[The prepared statement, plus attachments of Dr. Lyons follow:]

U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234
STATEMENT OF
JOHN W. LYONS, DIRECTOR
NATIONAL ENGINEERING LABORATORY
NATIONAL BUREAU OF STANDARDS

BEFORE THE

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATION AND OVERSIGHT
AND THE
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY
ON THE
EARTHQUAKE HAZARD REDUCTION ACTIVITIES
OF THE
NATIONAL ENGINEERING LABORATORY
NATIONAL BUREAU OF STANDARDS

May 23, 1984

Mr. Chairman and Members of the Subcommittee: It is a pleasure for me to appear before the Joint Meeting of these Subcommittees to discuss the earthquake hazard reduction efforts at the National Bureau of Standards (NBS). These activities are conducted primarily by the Center for Building Technology and are an integral part of the NBS building research program. I am accompanied by Richard N. Wright, Director of the Center for Building Technology.

INTRODUCTION

As the Nation's central physical sciences and engineering measurements laboratory, the NBS conducts research on performance criteria and supporting measurement technology for earthquake-resistant construction. Unique laboratory facilities support studies of the strength and energy absorption characteristics of

structural and geotechnical materials and systems. We develop methods to predict earthquake resistance during design, to assess resistance of existing facilities, and to measure properties of materials and systems.

The NBS provides technical support for the development, testing, and improvement of seismic design and construction provisions. These are incorporated in practices for Federal construction and are used in national standards and the regulations of State and local governments.

As specified in the Congressional directives and Presidential earthquake program, the NBS assists and cooperates with other Federal agencies, the National Institute of Building Sciences, professional organizations, model building code groups, and State and local building departments. Although the NBS has no role in the promulgation or the enforcement of building standards or codes, the technical support provided for organizations that do develop them is an effective means of getting research into practice.

NATIONAL BUREAU OF STANDARDS ROLE IN THE EARTHQUAKE HAZARDS REDUCTION PROGRAM

In implementing the National Earthquake Hazards Reduction Program (NEHRP) which resulted from the Earthquake Hazards Reduction Act of 1977 (P.L. 95-124) the President assigned NBS the following continuing responsibilities.

- Provide technical support to the building community, including the Federal agencies involved in construction, in continuing the development, testing, and improvement of model seismic design and construction provisions suitable for incorporation in local codes, standards (including Federal standards), and practices.

- Perform research on performance criteria and supporting measurement technology for earthquake resistant construction.

The NBS responsibilities address two problem areas: (a) safe and economical new construction and (b) assessment and mitigation of hazardous existing facilities.

It is important that new construction not add to the earthquake problem. Safe and economical new construction may be achieved by improved, nationally applicable seismic standards for new buildings. Structural, geotechnical, mechanical, architectural, and economic studies supported by the National Science Foundation (NSF) over the past 7 years have provided substantial advances in abilities to model and predict the earthquake response of buildings and its consequences. However, this knowledge must be synthesized to develop design criteria that will provide consistent safety among the various built elements and various materials or technologies for each. Moreover, design criteria must be developed to fit methodologies appropriate to the responsible design profession. Evaluation and measurement methods consistent with practices of design, manufacture, construction, and inspection must be developed to implement the design criteria.

Since existing hazardous buildings are probably the greatest source of danger to the population during a severe earthquake, it is also necessary to develop techniques to identify the most hazardous buildings, develop nondestructive methods to determine the properties of the buildings and their components in place, and define the strength and energy-absorbing capacity provided by various techniques of strengthening and repair.

The earthquake problem in the central and eastern U.S. is a particularly difficult problem. Most researchers to date have concentrated on practices in the areas of the U.S. where the probability of occurrence is greatest. We are now becoming more sensitive to the geographical areas that have a need to consider earthquakes in design where the probability of occurrence is not as high, but where the potential for losses may be as great. Broadly speaking, seismic design is not standard practice east of the Mississippi. There is no detailed survey available on seismic design practices in the central and eastern U.S. for building structures and lifeline structures, but our experiences indicate that very little consideration is given to seismic design practices in these regions. For example, the trial design program of the Building Seismic Safety Council includes design of buildings in New York, Chicago, St. Louis, Memphis, Charleston, and Dallas/Ft. Worth. In all of these cities it is not routine to require seismic design. The chairman of the Committee on Electrical Power and Communications Lifelines of the Technical Council on Lifeline Earthquake Engineering of the American Society of Civil Engineers indicates that there rarely is consideration of seismic effects in design for power distribution and transmission systems in the Midwest.

In order to address these issues, the NBS program was established to (a) improve building design and construction practices by conducting fundamental research necessary to establish consistent standards that include reliable measures of the performance of buildings and their environment during an earthquake and (b) provide technical support in the development of seismic design standards for consideration and subsequent application in Federal construction and encouragement for the adoption of improved seismic provisions in State and

local building codes. Currently, the major thrusts of the NBS earthquake program include (a) improved design criteria and standards, (b) more reliable measures of the effects of natural forces on buildings, (c) safety evaluation of existing buildings, and (d) postdisaster investigations.

The NBS laboratory research program is designed to provide the necessary information on which to base advanced structural design criteria for improving seismic response of new and existing building structures. It is aimed at meeting the most urgent research needs for filling gaps in building codes and standards and developing new criteria and making recommendations for repair and retrofit of existing structures. The research is conducted in cooperation with other government agencies, practicing engineers and architects, professional organizations, trade associations, building owners, products manufacturers, standards and regulatory organizations, and university researchers. In planning this work, close liaison is maintained with these individuals and organizations. These interactions assist in identifying and assigning priorities to research problems in earthquake engineering. They also ensure that NBS efforts are coordinated with other work.

NBS RESEARCH ACTIVITIES

The Center for Building Technology conducts analytical, laboratory, and field research to improve the performance of buildings and other structures subjected to earthquakes. Construction of a computer-controlled, three-dimensional testing facility for earthquake structural research was completed in 1983. This unique facility uses seven hydraulic actuators operating under computer control to apply three-dimensional, cyclic loads, and/or displacements.

Computer-controlled data acquisition and processing completes the testing facility.

The three-dimensional facility is currently being used in studying the basic energy-absorbing mechanisms and strengths of masonry shear walls subjected to simulated seismic loading. This research, with partial support from industry, is being conducted in order to develop rational design techniques for masonry shear walls. The research results will be useful for evaluating existing construction as well as for designing new construction. The results are particularly applicable to construction practices in the central and eastern U.S. which presently use little or no reinforcing steel. Results of this research will be implemented through active staff participation on technical committees such as the Masonry Standard Committee sponsored jointly by the American Concrete Institute and the American Society of Civil Engineers.

Additional research efforts include improved in situ testing techniques for use in site evaluation and studies on the cyclic strain approach to the evaluation of the potential for soils to liquefy during earthquakes. Soil liquefaction, a phenomenon in which the soil behaves somewhat like a viscous fluid, is a potential problem throughout the U.S. including the central states. Liquefaction has been observed in many earthquakes, including the 1811-1812 New Madrid, Missouri Earthquakes. NBS research results are used in the Standard Penetration Test of the American Society for Testing and Materials (ASTM).

In October 1983, NBS conducted field research in Japan in areas that underwent liquefaction during a recent Japanese earthquake. These studies provide the relationship between U.S. and Japanese soils characterization required for

U.S. practices to benefit from Japanese earthquake experiences. This work was conducted in cooperation with the Japanese government and Japanese industry. Several U.S. Federal agencies provided support to NBS to conduct this work which included collecting data using both U.S. and Japanese test procedures.

Large-scale testing is an important component of the NBS structural laboratory work. Current work on large-scale bridge columns will provide data that are not currently available on the behavior of large columns in earthquakes. Both full-scale performance and the effect of size on test results will be studied to determine if research on small-scale specimens can be safely and economically extrapolated by structural mechanics modeling to the large sizes actually being used in bridges. This work is being supported by NBS, the Federal Highway Administration, the NSF, and the California Transportation Department.

IMPROVED SEISMIC PRACTICES

NBS has worked closely with the Federal Emergency Management Agency (FEMA) in establishing and supporting the Federal Interagency Committee on Seismic Safety in Construction (ICSSC) and in the non-Federal Building Seismic Safety Council (BSSC). NBS, along with others, has assisted FEMA in its review and planning of earthquake-related Federal research. These efforts have led to considerable progress in developing improved seismic design provisions for building codes and improved standards and practices for both private and Federal construction.

The ICSSC, made up of representatives of 23 Federal agencies with construction-related programs and chaired by NBS, currently is solving a number of problems of importance to the Federal Government including: a uniform seismic design standard for Federal agencies, practices to identify and correct existing

hazardous buildings, practices for the safety of lifelines, practices for site hazard assessment, practices for Federal domestic assistance, lease, and regulatory programs, and response of the ICSSC to damaging earthquakes. In addition to its role as Chair, NBS is providing technical support for these activities. NBS and the ICSSC are cooperating with the BSSC, with ICSSC members participating on BSSC technical committees and Board. Additional information on the ICSSC is contained in attachment A.

At the request of FEMA, NBS has provided technical support throughout the BSSC's program for evaluating seismic design provisions. With financial support from FEMA, NBS worked with the BSSC Trial Design Overview Committee to prepare a trial design plan for evaluation of seismic provisions being studied by the BSSC and to prepare a report on amended seismic provisions to be used as the basis for the trial designs. Additional studies are being conducted as the Trial Design Program continues.

BSSC will develop its recommendations by consensus balloting procedures. Results of BSSC's trial designs of nearly 50 buildings in 9 cities (Los Angeles, Seattle, Phoenix, Memphis, New York, Chicago, St. Louis, Charleston, and Dallas/Ft. Worth) will be reported to BSSC members in Arlington on May 31. Seismic design provisions based on the trial designs will be sent to BSSC members in July 1984. BSSC plans to recommend provisions for adoption in national standards and model building codes at the completion of the balloting. Additional information on the BSSC is in attachment B.

INTERNATIONAL ACTIVITIES

I described earlier some of our laboratory facilities and some of the research projects using them. Yet, earthquake problems are certainly not limited to the U.S., east or west, nor do they recognize any political boundaries. Many countries are conducting earthquake-related research but no one country can solve all of the problems. In order to conserve resources, coordination of earthquake research is necessary. We actively support and participate in such coordinated efforts.

For example, the Panel on Wind and Seismic Effects of the U.S./Japan Program on Natural Resources (UJNR) met at NBS only last week. This was an intensive exchange of technical information between the U.S. and Japan. Fourteen Federal agencies participated in this exchange.

Through its leadership of the Panel on Wind and Seismic Effects, NBS has encouraged, along with NSF, the formulation of a cooperative program on large-scale structural research. With funding from NSF, research is now underway in Japan and the United States on steel structures. Laboratory work on the seismic resistance of reinforced concrete structures is complete and a program on masonry is being planned.

The research on bridge columns, which I have described, is not only a cooperative effort of Federal agencies and State agencies but is being coordinated through the UJNR. This exchange of research results will be very valuable to both countries.

These cooperative efforts were initiated as a result of a need to share facilities. The large-scale structural research program allowed the U.S. to

take advantage of the Japanese capability to test full-scale structures as tall as seven stories. Improvements in the research facilities at NBS such as the tri-directional testing facility and large-scale testing facility, will result in more effective NBS participation in these programs. NBS cooperative research programs with other countries include:

- a cooperative program with the French national laboratory for building research (Centre Scientifique et Technique du Batiment), which includes a project on seismic repair and retrofit of existing buildings; and
- cooperative programs with Yugoslavia on seismic design criteria, including the same criteria being evaluated by the BSSC; masonry shear wall resistance to seismic loading; bridge columns; and potential of soils to liquefy.

NBS represents the United States on the Conseil International du Batiment pour la Recherche L'Etude et la Documentation (CIB) [International Council for Building Research Studies and Documentation]. U.S. participation in the CIB has led to the establishment of an international working commission on earthquake hazards reduction, which is chaired by a representative of NSF. NBS also participates as a member of a control board to improve seismic design requirements of Algeria, with the U.S. Geological Survey (USGS) providing overall guidance for the control board.

IMPLEMENTATION

The success of Federal programs for achieving earthquake hazards reduction can be measured in terms of the extent to which the results are used by various

mission agencies and private sector building owners and users and the extent to which the results are incorporated in new standards and improved design practices. The working relationships that NBS has established with groups throughout the building community provide an effective means for achieving this implementation. NBS building research staff participate actively in standards development in the private sector as well as at Federal, State, and local levels, with 67 different staff members participating in 270 distinct standardization activities. These implementation and coordination efforts have resulted in the adoption of research findings in standards and codes. For example, NBS serves as Secretariat of the American National Standards Institute Committee A58, which is responsible for developing the voluntary consensus standard entitled Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. This national standard for design loads, including earthquake, was revised in 1982.

We conduct workshops for other Federal agencies to become acquainted with our earthquake research results and we participate in workshops put on by other agencies. As an example we have presented papers at workshops conducted by the USGS in the Central U.S. and elsewhere.

CLOSURE

I have included a list of some of our accomplishments in Attachment C.

This concludes my formal statement. I would be pleased to answer any questions you may have.

INTERAGENCY COMMITTEE ON SEISMIC SAFETY IN CONSTRUCTION FACT SHEET

All 50 states in the U.S. are vulnerable to the hazards of earthquakes, and at least 39 of them are subject to major or moderate seismic risk. Earthquakes have caused, and can cause in the future, enormous loss of life, injury, destruction of property, and economic and social disruption. Such losses, destruction, and disruption can be reduced substantially through the development and implementation of earthquake hazards reduction measures. Recognizing these needs, the Congress passed the Earthquake Hazards Reduction Act of 1977 (P.L. 95-124), and the President established the National Earthquake Hazards Reduction Program (NEHRP) the following year. The Act and the NEHRP acknowledge that the Federal government must set an example for others to emulate by its own actions, including the institution of more effective hazards mitigation in its own facilities.

The NEHRP established the Interagency Committee on Seismic Safety in Construction (ICSSC) in 1978 to assist the Federal departments and agencies involved in construction to develop earthquake hazards reduction measures and to incorporate them in their ongoing programs. These measures will be based on nationally recognized standards and practices to the extent feasible and consistent with Federal responsibilities. Specific objectives cited in the NEHRP include:

- develop seismic design and construction standards for Federal projects,
- develop guidelines to ensure serviceability following an earthquake of vital facilities constructed or financed by the Federal government,
- develop guidelines that provide for independent State and local review of seismic considerations in the construction of critical facilities constructed and financed by the Federal government where appropriate,
- develop a strategy to identify existing Federal buildings and other structures that pose unacceptable earthquake-related risks,
- coordinate the development of guidelines for the consideration of seismic risk in the development of Federal lands.

ICSSC cooperates with State and local governments and private organizations in the development of nationally applicable earthquake hazard reduction measures. It is represented on the board of the Building Seismic Safety Council and has a representative on each technical committee of BSSC.

Using consensus procedures, the ICSSC recommends earthquake hazard reduction practices suitable for use by Federal agencies. ICSSC recommended practices will not be mandated for use by Federal agencies except by Executive Order, but they may be adopted as required practices by the various Federal agencies following their established practices for implementing regulations.

All Federal departments and independent agencies that are involved in construction are invited to participate in the ICSSC. Involvement in construction includes:

- agencies responsible for the construction, operation, or maintenance of facilities that may be hazardous in an earthquake situation to Federal employees, occupants, or the general public;
- agencies that lease, finance, assist, or regulate the construction, operation, and maintenance of facilities whose performance in an earthquake

environment may lead to hazards to the public;

- agencies conducting research and development programs that provide technical bases for earthquake hazard reduction practices for the construction, operation, and maintenance of public and private facilities.

Each participating department or independent agency is represented by a senior person. Additional Federal agency personnel serve on technical subcommittees. Persons from the private sector may be invited to participate in ICSSC activities as observers. The ICSSC is chaired by Richard N. Wright, Director, Center for Building Technology, National Bureau of Standards.

The technical program of the ICSSC is conducted by four subcommittees. Missions of the subcommittees are as follows:

Subcommittee 1 - Standards for New and Existing Buildings
National Bureau of Standards, Chair

The mission is to recommend seismic design and construction standards for new and existing Federal buildings, their appurtenances and nonstructural components. This includes development of strategies and techniques for the identification and correction of existing seismically hazardous buildings.

Subcommittee 2 - Lifelines
Federal Highway Administration, Chair

The mission of this Subcommittee is to identify existing guidelines or standards for seismic design, construction and retrofit of energy, transportation, water, and telecommunication systems; to recommend Federal adoption of such standards when found adequate; and to encourage development of new standards where there are significant omissions. The subcommittee will study techniques for evaluating the seismic vulnerability of existing lifelines and for improving their resistance to seismic effects and ease of repair.

The Subcommittee also will consider strategies which will permit identification of those lifeline facilities important in the emergency,

immediate recovery, and long-term economic recovery periods, and provide guidelines for appropriate levels of seismic protection for each type.

Subcommittee 3 - Evaluation of Site Hazards
U.S. Geological Survey, Chair

The mission is to establish guidelines, procedures, and criteria for site selection and the evaluation of seismic risk and seismically induced geologic hazards to Federally funded, assisted, and regulated construction sites. Hazards that are to be considered include: seismicity, ground shaking, surface faulting and other tectonic deformation, liquefaction, landslides, and tsunamis.

Subcommittee 4 - Seismic Practices for Federal Domestic Assistance, Leasing, and Regulatory Programs
Environmental Protection Agency, Chair

The Subcommittee will develop strategies for implementation of appropriate standards for earthquake-resistant design and construction of structures and facilities involving Federal domestic assistance (aid, grant, loan, mortgage insurance), leasing, and regulatory programs.

The Subcommittee will deal primarily with policy matters related to application of mandatory standards or guidelines for Federal domestic assistance, leasing, and regulatory programs, with consideration of State and local codes. Recommendations will be formulated for the implementation of mandatory standards and guidelines and for required regulatory procedures which can be adopted by individual agencies. Specific requirements and exceptions to the mandatory standards and guidelines will be developed for Federal assistance and leasing programs.

Proper coordination will be maintained between all related regulatory organizations and other Federal, State, and local agencies involved in construction under Federal domestic assistance, leasing, and regulatory programs; to assure resolution of conflicts prior to adoption of mandatory seismic standards.

The ICSSC develops technical publications including recommended practices and technical reports. The following is a list of publications and reports in progress, and planned reports:

Publication

Draft Seismic Standard for Federal Buildings.
Washington, DC: National Bureau of Standards, NBSIR 81-2195, 1981.

Available from: National Technical Information Service
Springfield, VA 22161
Order No. - PB81-163842

Evaluation of Potential Surface Faulting and Other Tectonic Deformation.
 Reston, VA: U.S. Geological Survey, Open File Report 82-732, 1982.

Available from: USGS Open File Service Section
 Box 25425
 Federal Center
 Denver, CO 80225

Evaluation of Earthquake-Induced Ground Failure.
 Reston, VA: U.S. Geological Survey, Open File Report 82-880, 1982.

Available from: (Same as above)

Reports in Progress

Evaluation of Individual Seismic Sources

Evaluation of Seismic Wave Attenuation

Evaluation of Site Hazards and Decisionmaking in Earthquake-Resistant Design

Evaluation of Site-Specific Effects of Soil and Rock on Ground Motion

Evaluation of Tsunami Hazards

Principles for Selecting Earthquake Ground Motions in Engineering Design

Planned Reports

Evaluating and Strengthening or Abating Existing Hazardous Buildings

Assessment of Federal Involvement in Lifeline Seismic Problems

Assessment of Seismic Standards Applicable Under Federal Domestic Assistance,
 Leasing, and Regulatory Programs

Workshops

Three workshops have been held in 1984, a fourth will be held.

- Implementing Federal Seismic Provisions in the Building Program of Federal Agencies
- Lifelines
- Seismic Risk Mapping

A fourth workshop on hazardous existing buildings is planned.

Information about the activities of ICSSC may be obtained from:

ICSSC Secretariat
 Room B168, Building 226
 Center for Building Technology
 National Bureau of Standards
 Washington, D.C. 20234
 301-921-2140

BUILDING SEISMIC SAFETY COUNCIL FACT SHEET

- The purpose of the Building Seismic Safety Council is to enhance the public's safety by providing a national forum to foster improved seismic safety provisions for use by the building community. For the purposes of the Council, the building community is taken to include all those involved in the planning, design, construction, regulation, and utilization of buildings.
- The scope of the BSSC's activities encompasses seismic safety of building-type structures with explicit consideration and assessment of the social, technical, administrative, political, legal, and economic implications of its deliberations and recommendations.
- The BSSC recognizes that appropriate earthquake hazard reduction measures and initiatives should be adopted by existing organizations and institutions and incorporated into their legislation, regulations, practices, rules, codes, relief procedures and loan requirements, whenever and wherever possible, so that these measures and initiatives become part of established activities rather than being superposed as separate and additional.
- The BSSC is established as an independent, voluntary body under the auspices of the National Institute of Building Sciences.
- The membership of the BSSC is open to all professional societies, and labor, trade, model code, voluntary standards, public interest, and public agency organizations which have an interest in the Council's purpose. Organizations not meeting these requirements, but nonetheless interested in pursuing the purpose and objectives of the Council may petition and be elected to membership by the Board of Direction. The Council will make a reasonable effort to create and maintain a membership that is a broad and balanced representation of all segments of the building community and the public interest.
- To achieve its purpose, the BSSC does the following:
 - a. promote the development of seismic safety provisions suitable for use throughout the United States;
 - b. recommend, encourage, and promote the adoption of appropriate seismic safety provisions in voluntary standards and model codes;
 - c. assess implementation progress by Federal, State, and local regulatory and construction agencies;

- d. identify opportunities for the improvement of seismic regulations and practices and encourage public and private organizations to effect such improvements;
- e. promote the development of training and educational courses and materials for use by design professionals, builders, building regulatory officials, elected officials, industry representatives, other members of the building community, and the public;
- f. provide advice to governmental bodies on their programs of research, development, and implementation; and
- g. periodically review and evaluate research findings, practice, and experience and make recommendations for incorporation into seismic design practices.

A major BSSC effort is currently underway to improve seismic design provision. The following activities are completed or in progress:

- BSSC seeks to produce recommended provisions for seismic design and construction of new buildings. Recommendations will be sent to BSSC membership in July 1984 for ballot.
- Complete assessment and balloting of provisions for trial designs. (January 1981).
- Complete plan for conduct of trial design program. (November 1982).
- Complete amended provisions for use in trial designs. (December 1982).
- Phase 1 trial designs in Los Angeles, Seattle, Memphis, and Phoenix completed. (April 1983).
- Phase 2 trial designs in New York, Chicago, Charleston, St. Louis, and Ft. Worth/Dallas completed. (May 1984).
- The fifth Annual Meeting of the BSSC will be held on May 31-June 1, 1984, in Arlington, Virginia. The meeting will focus on the findings and conclusions of the trial designs using amended provisions, and recommendations for additional change as a result of the trial design program. Plans for future activities will also be discussed.
- Recommended provisions to be balloted in July 1984.
- NBS has provided technical support to the BSSC throughout the assessment of the provisions and evaluation of the trial design results.
- Education and dissemination programs are part of the objectives of the BSSC. They have not, as yet, completed plans in this area. Instead, they have been concentrating on completing the trial design program.

NBS ACCOMPLISHMENTS

- Earthquake Investigations
- Research and Development Program Planning
- Studies for Standards
- Laboratory Research
- Various Professional Activities

A list of past accomplishments in these areas is attached.

ACCOMPLISHMENTS*

EARTHQUAKE INVESTIGATIONS

- Briefed House Committee on Public Works on the damage caused by the San Fernando Earthquake of February 9, 1971 and documented building performance. (OEP, DoD, NBS)

— Lew, H. S., Dikkers, R. D., Leyendecker, E. V., Pfrang, E. O., and Kramer, S., NBSIR-10556, "The San Fernando California Earthquake of February 9, 1971," 1971.

Lew, H. S., Leyendecker, E. V., and Dikkers, R. D., BSS-40, "Engineering Aspects of the 1971 San Fernando Earthquake," 1971.

- Made recommendations to the Nicaraguan government for the repair of severely damaged buildings. Conducted investigation at the request of the State Department of building damage caused by the 1972 Managua Earthquake. (USAID, NBS)

Wright, R. N. and Kramer, S., TN 807, "Building Performance in the 1972 Managua Earthquake," 1973.

- Conducted an investigation at the request of the State Department of building damage caused by the March 4, 1977 Romania Earthquake. Made recommendations to the State Department for the expenditure of U.S. funds provided to Romania for reconstruction following the earthquake.

Fattal, S. G., Simiu, E., and Culver, C., SP 490, "Observations on the Behavior of Buildings in the Romania Earthquake on March 4, 1977," 1977.

- Conducted an investigation of the Miyagi-ken-oki, Japan Earthquake of June 12, 1978 in cooperation with the FHWA, USGS, and EERI. (Earthquake Engineering Research Institute) (NBS)

Ellingwood, B., Editor, SP 592, "An Investigation of the Miyagi-ken-oki, Japan Earthquake of June 12, 1978," 1980.

- Conducted a survey of damaged caused by the 1979 Imperial County Earthquake in cooperation with the Earthquake Engineering Research Institute and contributed to EERI publication. (NBS)

"Reconnaissance Report - Imperial County, California, Earthquake, October 15, 1979," 1980.

* Organizations providing funding for each activity are indicated in parenthesis.

RESEARCH AND DEVELOPMENT PROGRAM PLANNING

- Worked with building community representatives and university researchers in a 1972 workshop to identify policies and priorities for improvement of building practices for disaster mitigation. (NSF, NBS)

Wright, R. N., Kramer, S., and Culver, C., Editors, BSS 46, "Building Practices for Disaster Mitigation," 1973.

- Worked with design professionals and university researchers to identify research needs for earthquake resistance masonry construction based on a national workshop. (NSF, NBS)

Crist, R. and Cattaneo, L., Editors, BSS 106, "Earthquake Resistant Masonry Construction: National Workshop," 1977.

- Worked with design professionals and university researchers and identified research needs and priorities for geotechnical engineering based on a national workshop. (NSF)

Lee, K. L., Marcuson, W. F., Stokoe, K. H., and Yokel, F. Y., Editors, Report, "Research Needs and Priorities for Geotechnical Earthquake Engineering Applications," 1978.

- Worked with the OSTP in establishing the Building Seismic Safety Council in 1978 to foster improved seismic safety. The BSSC consists of representatives of organizations that will promulgate, use, or be affected by seismic design standards. (NBS)
- Working with FEMA, NSF, and USGS, NBS participated in drafting in 1979 a Seismic Research Plan for 1981-1984. This effort, conducted under the auspices of the OSTP, was intended to assure a coordinated approach in the research efforts of the four agencies. (NBS)
- Worked with university and private researchers in 1979 to develop a recommended cooperative U.S. - Japan research program to be conducted under the auspices of the U.S. - Japan Panel on Natural Resources. NSF currently is funding a Cooperative U.S. - Japan Program in Large-Scale Structural Testing as a result of the joint effort. The program was extended in 1981. (NBS)
- Liaison member of NRC Committee on Earthquake Engineering Research in 1982 to review state of such research in the U.S. (NBS)
- Provide Chairman and Technical Secretariat to ICSSC in 1982. (FEMA/NBS)
- Currently working to develop coordinated masonry research program between U.S. and Japan. Have previously worked on programs in concrete and steel buildings. Bridge structures are in progress. (NBS/NSF)

STUDIES FOR STANDARDS

- Developed criteria for use by the Veterans Administration in evaluating the strength of unreinforced masonry in existing buildings for the purpose of determining their seismic resistance. This program was a result of the San Fernando Earthquake experience. (VA, NBS)

Fattal, S. G. and Cattaneo, L. E., NBSIR 74-520, "Evaluation of Structural Properties of Masonry in Existing Buildings," 1974.

- Developed procedures for use the Defense Civil Preparedness Agency for the evaluation of risks due to natural hazards in existing buildings. (DCPA)

Culver, C. G., Lew, H. S., and Hart, G. C., BSS 61, "Natural Hazards Evaluation of Existing Buildings," 1975.

- Developed recommendations for improving the building regulatory system for the government of Nicaragua. This was a result of the experience in the 1972 Managua Earthquake. (USAID, OAD)

Wright, R. N. and Lamana, A., TN 885, "A Technical Review of the Nicaraguan Building Regulatory System," 1975.

- Evaluated seismic criteria, at the request of the Federal Energy Regulatory Commission, proposed for use in liquefied natural gas facilities planned for California. Stated in 1977 and continuing. (FERC)
- Worked with design professionals and university researchers and developed tentative seismic design provisions incorporating the latest research results of NSF, NBS, and USGS. (NSF, NBS)

Applied Technology Council, SP 510, "Tentative Provisions for the Development of Seismic Regulations for Buildings," 1978.

- Worked with standard and code users and developed a program plan to facilitate implementation of the seismic design provisions described in SP 510 through model codes, voluntary standards, and regulatory groups at the Federal, State, and local level. This includes a plan to evaluate the impact of the tentative provisions of SP 510 prior to any implementation. (NSF)

Culver, C. G. and others, NBSIR 78-1549, "Plan for the Assessment and Implementation of Seismic Design Provisions for Buildings, 1978.

- Developed techniques and performed systematic study of the logic and the internal consistency of seismic design provisions of SP 510. (NSF, NBS)

Harris, J. R., Fenves, S. J., and Wright, R. N., TN 1100, "Analysis of Tentative Seismic Design Provisions for Buildings," 1979.

- Participate as part of the Interagency Committee on Seismic Safety in Construction which includes most of the Federal agencies. CBT provides the vice-chairman and acting chairman of the ICSSC. CBT serves on its Steering Committee, chairs two subcommittees and participates in four others. One of these, the subcommittee on Building Standards, is charged with developing uniform Federal provisions for seismic design. (NBS, FEMA)

Harris, J. R., Leyendecker, E. V., and others, NBSIR 81-2195, "Draft Seismic Standard for Federal Building," 1981.

- NBS is conducting technical studies of "Tentative Provisions for the Development of Seismic Regulations for Buildings," in cooperation with the Building Seismic Safety Council (formed by FEMA, NBS, and others). This effort will lead to provisions that have been broadly reviewed and that will be used as the basis for conducting trial designs for the purpose of impact assessment.

NBSIR 80-2111-1 through 11, "Review and Refinement of ATC 3-06 Tentative Seismic Provisions," A series of eleven reports reviewing specific areas of ATC 3-06, 1980.

- NBS participated in the technical study to develop a trial design plan to evaluate the "Tentative Provisions."

NBSIR 82-2589, "Plan for a Trial Design Program to Assess Amended ATC 3-06 Tentative Provisions for the Development of Seismic Regulations for Buildings," November 1982.

- NBS participated in the technical study to recommend amendments to the "Tentative Provisions for Use in Trial Designs."

NBSIR 82-2626, "Amendments to ATC 3-06 Tentative Provisions for the Development of Seismic Regulations for Buildings for Use in Trial Designs," December 1982.

- NBS serves as the Secretariat of American National Standards Institute's A58 "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures." This national standard for design loads (earthquake, wind, gravity, etc.) is a major vehicle for implementing research in work into the private sector.

LABORATORY RESEARCH (Numerous reports available, some recent samples are listed)

- Yokel, F. Y., Chung, R.M., and Yancey, C. W., "NBS Studies on Mobile Home Foundations," NBSIR 81-2238, March 1981.
- Kovacs, W. D., Salomone, L. A., and Yokel, F. Y., "Energy Measurement in the Standard Penetration Test," National Bureau of Standards, BSS Report #135.

- Kovacs, W. D. and Salomone, L. A., "SPT Hammer Energy Measurement," Journal of Geotechnical Engineering Division, ASCE, Vol. 108, No. GT4, April 1982.
- Kovacs, W. D., Results and Interpretation of SPT Practice Study, ASTM Geotechnical Testing Journal, September 1981.
- Dobry, R., Ladd, R. S., Yokel, F. Y., Chung, R. M., and Powell, D., "Prediction of Pore Water Pressure Buildup and Liquefaction During Earthquakes by the Cyclic Strain Method," National Bureau of Standards, BSS 138, Report.
- Dobry, R., Powell, D., Yokel, F. Y., and Ladd, R. S., "Liquefaction Potential of Saturated Sand - The Stiffness Method," Seventh World Conference on Earthquake Engineering, Istanbul, Turkey, October 1980.
- Dobry, R., Yokel, F. Y., and Ladd, R. S., "Liquefaction Potential of Overconsolidated Sands in Moderately Seismic Areas," to be published in the Knoxville Conference on Earthquakes and Earthquake Engineering of the Eastern U. S., September 1981.
- Woodward, K., Rankin, F., "Behavior of Concrete Block Masonry Walls Subjected to Repeated Cyclic Displacements," NBSIR 83-2780, October 1983.
- Wu, S.T., Leyendecker, E.V., "Lateral-Torsional Response of Structures Subjected to Seismic Waves," NBSIR 83-2727.

PROFESSIONAL ACTIVITIES (Selected examples)

- Established through the State Department, a joint U. S. - Japan group in earthquake effects (U. S. - Japan Panel on Natural Resources, UJNR, sub-panel on Wind and Seismic Effects) in 1969 in order to begin coordination of efforts on the two countries. NBS provides the chairman of the U. S. subpanel. (NBS)
- Technical arm of National Conference of States on Building Codes and Standards.

RICHARD H. WRIGHT

Date of Birth: May 17, 1932

Birthplace: Syracuse, New York

Education:

B.S., Civil Engineering, 1953

Syracuse University

M.S., Civil Engineering, 1955

Syracuse University

Ph.D., Civil Engineering, 1962

University of Illinois

Position:

Director, Center for Building Technology

National Engineering Laboratory

National Bureau of Standards

His professional experience includes: junior engineer with the Pennsylvania Railroad, 1953 to 1955; instructor, assistant professor, associate professor and professor of civil engineering at the University of Illinois at Urbana from 1957 to 1974; and at the National Bureau of Standards, Chief of the Structures Section, Building Research Division 1971 to 1972, Deputy Director-Technical, Center for Building Technology, 1972 to 1973, and Director, Center for Building Technology 1974 to present.

The Center for Building Technology (CBT) is the national building research laboratory. It conducts laboratory, field and analytical research. It develops technologies to predict, measure and test the performance of building materials, components, systems and practices. It works cooperatively with other organizations, private and public, to improve building practices, CBT does not promulgate or enforce building standards or regulations, but its results are widely used in the building industry and adopted by private and governmental organizations that have standards and codes responsibilities. CBT programs include: computer integrated construction, structural safety, earthquake hazards reduction, building physics, building equipment, quality of building materials, and cement hydration.

CBT has unique laboratory facilities and a staff of engineers and scientists of international reputation. Principal disciplines are structural, geotechnical, materials, mechanical and electrical engineering, physics, chemistry, architecture and behavioral sciences. Of the 100 professional staff members, 50 have earned doctoral degrees and 30 are registered engineers or architects. About 50 research associates sponsored by industry, visiting scholars from universities, and guest workers from foreign laboratories complement the professional staff.

Dr. Wright has published about 50 articles on computer-aided design, formulation and expression of design criteria, performance criteria for buildings, structural design methods for earthquakes and other dynamic loads, flow and fracture in structural metals and mechanics of thin-walled beam structures.

He is President of the International Council for Building Research, Studies and Documentation, Chairman of the Interagency Committee on Seismic Safety in Construction, U.S. Chairman of the U.S.-Japan Panel on Wind and Seismic Effects, member of the Board of the Lighting Research Institute (and was its founding Chairman), fellow of the American Society of Civil Engineers, and member of the International Union of Testing and Research Laboratories for Materials and Structures, Earthquake Engineering Research Institute, Sigma Xi, Phi Kappa Phi, and Tau Beta Pi. He registered as a professional engineer in New York in 1958 and as a structural engineer in Illinois in 1974.

He received the Gold Medal Award of the Department of Commerce in 1982 for distinguished achievement in the Federal Service, and the Special Presidential Award of the Illuminating Engineering Society of North America in 1983 for contributions to the organization of the Lighting Research Institute.

JOHN W. LYONS

Date of Birth: November 5, 1930

Birthplace: Reading, Massachusetts

Education: Degrees

Harvard University, A.B., Chemistry
1952

Washington University, A.M., Physical Chemistry
1963

Washington University, Ph.D., Physical Chemistry
1964

Positions:

Director

National Engineering Laboratory

National Bureau of Standards

As Director of the National Engineering Laboratory Dr. Lyons is responsible for NBS's research in applied mathematics, building technology, electronics and electrical engineering, energy conservation, engineering standards development, fire, manufacturing engineering and chemical engineering.

From April to December 1983 Dr. Lyons served as the Acting Deputy Director of the National Bureau of Standards.

Dr. Lyons was Director of the NBS Center for Fire Research until December 18, 1977, and was responsible for providing scientific and technical knowledge applicable to the prevention and control of fires.

Dr. Lyons served in various research and development positions at the Monsanto Company from 1955 to 1973. He specialized in the chemistry and uses of phosphorus-based chemicals including fire retardants. He served from 1971 to 1973 as a member of the ad hoc panel of fire research, a National Academy of Sciences evaluation panel for the National Bureau of Standards.

Dr. Lyons is author of two books: Viscosity and Flow Measurements and The Chemistry and Uses of Fire Retardants. He has contributed chapters to five other books and has written numerous papers and articles on technical or research topics. His early research interest was the physical chemistry of polyelectrolyte solutions, especially formation of complexes with metal ions. This work emphasized the behavior of inorganic polyphosphates and desoxy ribonucleic acid (DNA).

Dr. Lyons is a Fellow of the American Association for the Advancement of Science, Fellow of the Washington Academy of Science, member of the American Chemical Society (past chairman of the St. Louis Section), member of the American Institute of Chemical Engineers and member of Sigma Xi. He serves on the Advisory Committee for Engineering, National Science Foundation; Advisory Council, College of Engineering, University of Maryland; Board of Directors, National Fire Protection Association. He is serving on a special committee of the Maryland State Board for Higher Education to study the needs for engineering education. He was chairman of the Products Research Committee (1974-1979), a nine-member charitable trust administering a \$5M research fund on fire research; co-chairman of the US-Japan Natural Resources Panel of Fire Research (1975-1978). He received the Presidential Management Improvement Award in 1977 and the US Department of Commerce Gold Medal, also in 1977. In 1981 he received the Presidential Rank Award of Distinguished Executive.

Mr. GORE. Great. Well, thank you very much.

Let me ask some questions to this—to this panel.

First of all, Dr. Speck, scientists have known about the potential for great earthquakes in the Central United States since 1811. The National Hazards Reduction Program has been in effect since 1977. Neither the hazards, nor the national program to reduce the hazards is new, therefore. In light of that, how well prepared would you say the Eastern United States is for earthquakes?

Dr. SPECK. Mr. Chairman and members of the committee, I think we would have to say that Eastern United States is certainly not adequately prepared. We don't even fully understand the earthquake phenomena in many areas of Eastern United States, as you've heard this morning.

I think that we can show two important lines of progress, and that the first line of progress has to do with the earthquake hazard per se, and the kind of activities in terms of basic research and the kind of activities in terms of State and local preparedness that are underway in a region-by-region basis. And one of those certainly would have to be what we now have underway with CUSEPP and CUSEC.

The second area that I think needs to be pointed out or reiterated, is the IEMS process that FEMA is working with in respect to State and local governments, which is well underway, developing the capability to plan preparedness planning and mitigation response, recovery planning for all kinds of hazards. And this, I think, is very critical and, as I indicated, that is well underway in Eastern United States, as well as elsewhere in the United States.

Third, I would add that we now have the Federal plan which we expect to test at a table top exercise this summer, and ultimately test—and a full-field exercise next summer. And that has transferability to any area in the United States where there may be a catastrophic earthquake. And that alone represents a substantial step forward compared to where we have been in the past.

We're improving a number of things. Important advances are in motion. There is a great deal yet to be done. And, hopefully, this hearing will help even more to be accomplished.

Mr. GORE. Well, good. If there were a major—that's certainly our hope also, let me say.

Let me follow up that, though, by asking, if there were a major earthquake in the New Madrid area tomorrow, what emergency plans are currently in place that could prevent loss of life? Is there adequate emergency housing, communications networks, food supplies and the like?

The answer is essentially no to all those questions, isn't it?

Dr. SPECK. The answer is that each State has an emergency planning section somewhere in that State, which is planning to respond to all emergencies and disasters, with emergency operating centers—operational centers in major cities, and the State would also possess one. You have an outstanding center just outside of Nashville, as I had the opportunity to visit not long ago, and that is coordinated with the—the counties and municipalities. That is in place and is improving and would be available to provide all the kinds of functional responses that you have to.

In addition to that, the Federal plan is in place. It has yet to be exercised. And that would coordinate some 21 agencies that would be brought to bear from the Federal level——

Mr. GORE. Yeah.

Dr. SPECK [continuing]. To deal with this.

So at this point, those are the kinds of things that we would have to respond to the emergency.

If you are talking about things like mitigation, which is a fancy term for taking steps to reduce the impact of an earthquake, we aren't very far along in that anywhere in Eastern United States——

Mr. GORE. Yeah.

Dr. SPECK [continuing]. In terms of getting building codes and that, and there would be a loss of life because those things have not been put into building codes.

One of the things we learned, Coalinga and from San Jose, was that where we do have experience with seismic safety in building codes is that it certainly makes a difference in terms of the collapse of the buildings.

Mr. GORE. Well, I'm certainly impressed with the emergency management personnel in Tennessee. I know how hard they work, and I know what they have put into their task. But—and I didn't mean to imply earlier that they're not doing a good job. I think they are.

What I meant to imply was that, in the Eastern United States generally, this threat has not been taken very seriously until quite recently. And, as a result, plans of all kinds related to earthquakes are just not very far along. Is that a fair statement?

Dr. SPECK. Earthquake-specific plans? Yes.

Mr. GORE. Yeah.

Dr. SPECK. Even, in some areas, the basic scientific knowledge that we need is not——

Mr. GORE. Yeah.

Dr. SPECK [continuing]. Very far along, as you've heard.

Mr. GORE. Yeah. All right.

Now, FEMA has undertaken an indepth assessment of damage and casualties for six cities in the Central United States resulting from a great earthquake in the New Madrid region. I understand you're prepared to provide that very preliminary and, in some respects, not quite satisfactory effort pending the completion of a more formal study; is that correct?

Dr. SPECK. Mr. Chairman, what I would like to do would be to, in providing that, also provide you—and I'd ask for it to be drafted—a letter indicating areas where we've asked our colleagues in the other Federal family agencies to also review the report with a view to areas where we may want—to have it modified before it's formally issued.

Mr. GORE. Well——

Dr. SPECK. And that should arrive, I would hope to get——

Mr. GORE. Well, I hope so, too, and I appreciate that. We had been told earlier that it would be here today. And I want to assure you again on the record, as I did off the record, that we're not interested in promoting some undue alarm on the part of the public or the communities in the region affected. But we have oversight

responsibility in this area, and we look forward to seeing that study.

Now, if you could summarize some elements of that study orally, deleting those portions that you think are troublesome—let me just ask the general question. If an earthquake with a magnitude greater than 8 were to occur today along the New Madrid Fault, how much damage would you estimate that it would cause in loss of lives, property and income?

Dr. SPECK. Mr. Chairman, that question isn't quite as easy to answer as you and I would like to think. It would depend where along that fault zone it happened. It would depend critically on the time of day it happened, insofar as loss of lives would be concerned. We've had estimates that we might expect a loss of something in the neighborhood of \$50 billion in terms of property. As I've indicated, for the reason I've indicated, the loss of life, you get a fairly wide range. Indeed, that is precisely one of the things that we were taking a look at, is exactly—looking at those cities, what kind of damage might you expect and, thus, what kind of potential loss of life might you expect.

And I think you will find—I think we will find that you can't simply look at a city and say that an earthquake of a given magnitude in the fault zone will create this kind of damage throughout a city. One of the things, as we look more specifically at those cities that we find, is that we'll create different kinds of levels of damage at different areas in the city due to the topography and stratigraphy and the like.

Mr. GORE. I understand. Still, that's a pretty big figure. How does that compare with the potential damage from earthquakes in California?

Dr. SPECK. Mr. Chairman, if—we've got some figures here which indicate that you get different estimates for different areas on the San Andreas Fault and adjacent faults.

Mr. GORE. I see.

Dr. SPECK. In the southern end of the fault, where I think you probably have the greatest expectation of an earthquake in the next 30 years, preliminary estimates would say maybe \$17 billion in damage, and I've seen estimates of anywhere between 3,000 and 14,000 people would lose their lives.

As you move on up the San Andreas Fault area toward those sections that are considered less likely—

Mr. GORE. Uh-huh.

Dr. SPECK [continuing]. To have the immediate threat of an earthquake, the potential loss of lives and property becomes greater. And there, you know, if you had one along the whole fault, which is not considered likely, why, you'd be talking about something substantially in excess of what you'd expect from New Madrid.

Mr. GORE. I see.

But to take the most likely case in both instances, the damage estimates are roughly three times as large in the New Madrid area than in the San Andreas area.

Dr. SPECK. Mr. Chairman, if I may refer to a report that the agency released on the basis of research that was done for it, the estimate in terms of the southern San Andreas Fault in terms of

loss was 17 billion; in the Newport-Inglewood area, the potential was 69 billion; in Hayward, it was 44; and in northern San Andreas, it was 38. And I would be glad to make this available for the record.

Mr. GORE. I think that's appropriate. That's a much more accurate way of stating it than I just did, because, obviously, the estimates vary widely depending upon where along the fault the quake could occur. That's helpful to me. Thank you.

Now, the so-called lifeline systems—oil and gas pipelines, railroads, major trucking routes, water lines, natural gas lines. These should be constructed in the future with an awareness of earthquake hazards in these areas; is that correct? Would that be your recommendation?

Dr. SPECK. I would expect it to be, Mr. Chairman, because so many of these lifelines are critical, not only to the Central United States area, but they cross from the Southwest to the Northeast. We, as I indicated in my testimony, are getting the recommendations from the Building Seismic Safety Council. We expect by this next year to have those recommendations in terms of new building construction in the private sector. We expect this year to issue a contract to study what measures would be appropriate in terms of recommending retrofitting. And in fiscal year 1985, we would then expect to go to contract to obtain recommendations on what would be appropriate in terms of lifelines.

So we have the one coming on, we have the second ready to go this year, and the third next year that would specifically address the lifeline issue and the best way of dealing with it.

Mr. GORE. All right. Very good.

Dr. Hall, the National Science Foundation has research activities in the Divisions of Earth Sciences and Civil and Environmental Engineering. How much of that NSF-sponsored research on Earth sciences is equally applicable to western and eastern earthquakes?

Mr. HALL. We have \$28 million that the Foundation spends in earthquake-related research, of which \$8 million is in earth sciences related area, and \$20 million in engineering. And we feel that the research in these areas, the research being carried out, is applicable pretty much throughout the United States. It would be very difficult to say that a particular piece of research was applicable to only one area of the United States.

Mr. GORE. Is that mike on? Is there a switch down there?

Dr. HALL. Maybe I'm not speaking—

Mr. GORE. OK.

Dr. HALL [continuing]. As closely to it as I should.

Mr. GORE. That's fine. No. That's fine.

Dr. HALL. So it would be very difficult.

In fact, we would claim that the work done in one area is applicable to other areas of the United States. You may remember my testimony. I said that we spend about a third of our money in California, a third in the East, and the other third in the West outside of California. So—and the results from one area apply to the other.

Mr. GORE. All right. Very good.

Now, in the Western United States, most people have at least some awareness of the risks of earthquakes. East of the Rockies, fewer people think about making their homes earthquake resistant,

and few would know how to protect themselves in the event of an earthquake.

Do you think the NSF's Societal Response Program is adequate at the current time, or do you think it should be changed?

Dr. HALL. I would argue for increasing support for that area, inasmuch as it was reduced drastically last year. And we were working primarily in four areas: The social and economic aspects of mitigation, preparedness, disaster impacts and responses, and research on hazard information dissemination. As a result of our reduction in the budget, we have minimized the last two, and we are now emphasizing only the social and economic aspects of mitigation and preparedness. And we feel strongly that that amount of funding that was available before should be reinstated in the future to be able to bring our activities up across the board in the area of societal response.

Mr. GORE. Uh-huh.

Just about a month ago, on Easter Sunday, I believe there was an event 4.1 on the Richter scale in Lancaster, Pa; is that correct?

Dr. HALL. This is out of my area, but we'll have some—

Mr. GORE. I see some expert heads nodding in the back of the room.

Dr. HALL. Dr. Wright—Dr. Wright is my backup in this area.

Mr. GORE. Well, with that, let me recognize my colleague, Mr. Walker.

Mr. WALKER. I have no questions—

Mr. GORE. All right.

Mr. WALKER [continuing]. Mr. Chairman. But we did, in fact, have a 4.1 on the Richter scale earthquake, and it was centered in Marticville, Pa.

Mr. GORE. It was—is that in Greater Lancaster?

Mr. WALKER. In Greater Lancaster. [Laughter.]

Mr. GORE. I think it was felt in seven States, including Washington, DC.

Dr. Lyons, one of the major considerations in earthquake preparedness is the cost of building construction. In percentage terms, how much would you estimate you would have to add to the cost of a new building in order to make it earthquake resistant?

Dr. LYONS. I think it depends a great deal on the experience of the designer. And our preliminary information is that if you give a building design to an architect who has worked in an area such as southern California where you're worried about this, that the increase in cost is either nil or a very few percent. If you give it to an inexperienced person and say all of a sudden you've got to add all these extra provisions, it may be as high as, say, 10 percent or so.

Mr. GORE. But what you're saying is that if this practice of making buildings earthquake resistant became relatively routine in areas near faults, then the extra cost, with experience, would become almost negligible; is that what you're saying?

Dr. LYONS. We think so. If you design the building with an earthquake in mind, you just don't do certain things. A lot of it is avoiding the kind of construction that we now know is vulnerable to earthquakes.

Mr. GORE. Well, that's very interesting. Are there some tradeoffs, some unappealing tradeoffs, that are not in the area of cost?

Dr. LYONS. Well, let me ask Dr. Wright to comment on that. He's our expert.

Mr. WRIGHT. One of the greatest problems in getting earthquake resistance economically comes when you have your irregular systems of resistance, either horizontally or vertically, so that one tradeoff would be a reduction in the freedom of the architect to arrange spaces and spectacularly-appearing buildings—

Mr. GORE. Uh-huh.

Dr. WRIGHT [continuing]. Because these often get rather hard to tie together—

Mr. GORE. Uh-huh.

Dr. WRIGHT [continuing]. To resist the earthquake forces and motions.

Mr. GORE. Uh-huh.

Dr. WRIGHT. So, while for a particular function you can build an earthquake-resistant building with very modest additional cost of a few percent, it will restrict you in the types of materials and the types of systems and the types of framing appearance that you can use, if you want to keep the cost down.

Mr. GORE. Some Hyatt hotels would not be the best place to stay in an earthquake. [Laughter.]

I said that. You don't have to. Although you're immune from suit as a result of your testimony here. [Laughter.]

All right. Now, that's very interesting, though. It's very interesting because this is important to building code people in cities like Memphis and other cities where they're trying to figure out how seriously to take this, because it's important to note that the cost need not be very high. In fact, there need not be any extra cost if the architectural and engineering communities integrate this awareness into their normal design practices. You'd agree with that, right?

Dr. WRIGHT. I'd say the additional cost would be very modest, once we get over the hurdle of knowing how to do it. The learning cost is not negligible for that architect or engineer.

Mr. GORE. Yeah, yeah. OK.

Now, in 1971, there was an earthquake in San Fernando, and several buildings that were designed to the specifications of the earthquake codes, including a new hospital, failed. Why? Are the lessons learned from these failures being applied in new codes, and specifically in the activity in the Eastern part of the United States?

Dr. WRIGHT. The failure in San Fernando of the relatively new Olive View Hospital did occur with a building that met the codes at the time it was constructed, in a general way.

It was interesting that the codes were modified between the time that building was designed and the time that the earthquake occurred in a way that would have increased its resistance. It's also interesting to note that, while the failure of the main hospital building was such that it had to be torn down and replaced, to a substantial extent, it met the intent of the code, which was that the building should not collapse in a strong earthquake. It didn't.

Now, the second part of your question, so that—in answer to the first part, we do learn from earthquakes. It's one of the most important learning mechanisms we have. And we do improve inadequate aspects of our practices from the lessons that we learn, and

we will continue to learn lessons, though most of the lessons from earthquakes are learning lessons we already knew, mistakes that have been repeated.

Now, if I—I'll try to answer the second part of your question briefly. You may want to followup because I may miss the main point of it.

In the Eastern United States, most designers, most builders, most regulatory authorities, have not taken earthquake risks seriously and have not attempted to design and construct buildings that would be resistant to earthquakes. Therefore, a lot of the existing buildings are quite vulnerable to earthquakes.

Mr. GORE. I'm looking at a picture here of the old building and the new building side by side. It might be interesting—

Dr. WRIGHT. At the Veterans' Administration site?

Mr. GORE. Yeah. The old one didn't fare too well, did it?

Dr. WRIGHT. The old one was the major cause of the life loss. Of some 60 people that died in that earthquake, most of them were in that one building.

Mr. GORE. Forty-five were in that one building. And the other building had to be redone, but, as you say, it didn't collapse.

Dr. WRIGHT. It didn't collapse.

Mr. GORE. It didn't kill people.

Dr. WRIGHT. Uh-huh.

Mr. GORE. How do we know if a building designed to meet the earthquake codes is really safe?

Dr. WRIGHT. A building designed and constructed to meet the existing up-to-date earthquake regulations, such as the ones used in California, the uniform building code or the recommendation of the Structural Engineers Association of California, these have been shown to be safe by—in general, for the ordinary building—by successful performance in severe earthquakes. For instance, in Coalinga, CA, the modern buildings designed in accord with the current codes survived quite well. The damages occurred to older buildings that were constructed before earthquake codes were formulated and enforced in the town.

Mr. GORE. Well, very good. That's quite interesting.

I have other questions that I'd like to ask all of you, but we've run very late and past lunch, and it is unfair to the other witnesses. I certainly want to yield to my colleague, Mr. Walker.

Mr. WALKER. I thank the gentleman for yielding, and I appreciate his indulging my sitting in on the subcommittee today.

Mr. GORE. Sure.

Mr. WALKER. It is a topic that has become of some interest in my area because of the recent seismic activity.

The one thing that I ran into that was kind of interesting—and maybe you can tell me how widespread this is, the fact that no homeowner's insurance policies in our area had earthquake provisions in them, and it kind of became common knowledge there that you were not protected.

Is it pretty standard fare that not very many people in the East are protected at all with any kind of earthquake protection?

Dr. WRIGHT. To my knowledge, not only are people in the East not covered under their homeowner's policy against earthquakes, but neither are people in the West. You have to specifically seek

earthquake coverage. It is available, it's not terribly expensive, but you don't get it without trying.

Mr. WALKER. So, in other words, if we were to have a fairly significant earthquake anywhere in the country, but particularly in the East where we have not designed homes and buildings to earthquake standards, the fact is there would be a major public expense involved in the rebuilding because virtually no one would have insurance protection on their homes or on the businesses. Is that—

Dr. WRIGHT. That's correct. There'd be a lot of people probably saying my house was damaged by fire, not by earthquake.

Mr. WALKER. I think that's rather logical. And you're right, it is inexpensive. After the one rumble through Lancaster the other day, and I talked to an insurance agent and he told me I didn't have protection, I called up and found out what I—talked to get protection. It's about \$4 a year is what it ended up costing to put it on my policy. I figured for that I could afford it and added it to my policy.

But it is something that I think very few people across the country understand, that in the event of damage from earthquake, even cracks, structural cracks, from a fairly minor earthquake, they would not be properly protected.

I thank the gentleman very much for yielding.

Mr. GORE. Very interesting addition to the record, and something that people in Memphis, TN would certainly want to know about also.

Let me thank the members of this panel. I wish we had more time to spend together. But I appreciate your statements very much, and your responses to the questions. Dr. Speck, we look forward to that study, and look forward to working with you on your continuing efforts. I think you all are doing a very good job over there. Thank you all very much.

Our last panel is made up of Dr. Robert M. Hamilton, chief geologist with the U.S. Geological Survey, based out in Reston, VA; accompanied by Dr. John R. Filson, chief of the Office of Earthquakes, Volcanoes and Engineering; and Mr. Robert B. Minogue, director of the Office of Nuclear Regulatory Research with the Nuclear Regulatory Commission.

Gentlemen, I want to thank you for being here. I want to apologize for the lateness of the hour and the fact that we've gone through lunchtime. I appreciate your indulgence very much.

In view of the lateness of the hour, if you could keep your oral presentations relatively short, between 5 and 10 minutes, the subcommittees would appreciate it. Without objection, your entire prepared statements will be included in the record, but we would appreciate you summarizing those statements if they are going to run longer than 5 to 10 minutes.

Dr. Hamilton, we'd like to begin with you. And I'd like to welcome you and invite you to proceed.

STATEMENTS OF DR. ROBERT M. HAMILTON, CHIEF GEOLOGIST,
U.S. GEOLOGICAL SURVEY, RESTON VA, ACCOMPANIED BY DR.
JOHN R. FILSON, CHIEF, OFFICE OF EARTHQUAKES, VOLCA-
NOES AND ENGINEERING; U.S. GEOLOGICAL SURVEY; AND
ROBERT B. MINOGUE, DIRECTOR, OFFICE OF NUCLEAR REGU-
LATORY RESEARCH, NUCLEAR REGULATORY COMMISSION,
WASHINGTON, DC

Dr. HAMILTON. Thank you very much, Mr. Chairman.

I will just let my written statement stand in the record and not summarize it in detail. But what I would like to do is use some posters that I have on the side of the room and make just a few points which I think would be of interest.

However, before I start that, I would like to comment on that last question that was raised previously, that involving insurance. Although it is true that earthquake insurance is relatively low in cost, however, there is a fairly large deductible that goes with that. And it's been a while since I've looked into it, but I believe that often earthquake insurance carries something like a 5- or 10-per-cent deductible, which means that you have—the first 5 or 10 per-cent of the value of your house, your whole house, is paid by you before you start collecting on your earthquake insurance. So if you have a \$100,000 house, the first \$5,000 or \$10,000 come out of your own pocket.

So, that usually dissuades people in remote areas from purchasing earthquake insurance. I've considered it myself and decided it wasn't worth the money because of the large deductible.

So, with that, I'd like to step to the side and proceed with a few posters.

[Poster shown.]

Dr. HAMILTON. This is a poster that was shown briefly in a slide before. But I wanted to call your attention to it again, because what it shows is the area affected by four different earthquakes in the U.S. history. Of course, here we have the area affected by the New Madrid earthquakes of 1811 and 1812. This is the area affected by the Charleston earthquake of 1886. This is the area affected by the San Francisco earthquake of 1906, and the area affected by the San Fernando earthquake of 1971.

The important point here is that the San Fernando earthquake and the Charleston earthquake were of comparable magnitude, as were the San Francisco earthquake and the New Madrid earthquake. In other words, these were a magnitude of 8-plus, and these were a magnitude of about $6\frac{1}{2}$ to $6\frac{3}{4}$. And one has to be impressed by the much greater felt area of the Eastern earthquakes compared with the Western earthquakes.

And if Congressman Brown were here, I'd try to use this to point out that really the problem in the East is really exaggerated by this effect of the much greater propagation of energy in the East. And this is a very important point.

Mr. GORE. Is that greater or magnified?

Dr. HAMILTON. The seismic waves travel to greater distances for the same amount of energy release in the East compared with the West, which means that, although we have earthquakes less often

in the East, when they do occur, they affect a much larger area, so there's a compensating factor.

[Poster shown.]

Dr. HAMILTON. This is a figure to show that earthquakes don't occur only in the New Madrid area and in the Charleston area, but they occur widely over the Eastern United States. This figure shows earthquakes of intensity 10 to 12 with the red dots—and you can see that the only areas such are in the New Madrid area and the Charleston area—and then, as Professor Nuttli referred to earlier, there are areas up in the St. Lawrence Valley similarly of this intensity.

Mr. GORE. Now that's the Mercalli scale of—

Dr. HAMILTON. This is the Mercalli scale of intensity which measures the effects of an earthquake, as opposed to the Richter scale which measures the energy released by the earthquake.

Mr. GORE. OK.

Dr. HAMILTON. OK.

Then the main point I'm trying to make here, though is to draw your attention to the intensity 5 and 6 and 7 and through 9. These are intensities that you can see affect a good part of the Eastern United States, and an intensity of 6 and above can cause significant damage.

So this reemphasizes the point made earlier that virtually every State in the East does have the potential—although significant earthquakes haven't really occurred in North Dakota or even in southern Florida—but, nevertheless, it is a problem for the whole East.

[Poster shown.]

Dr. HAMILTON. This is a figure that shows the plates of the Earth. And I think this is important to take into account, because it helps to explain the difference we have in the East compared with the West in understanding earthquakes.

This is the United States here and Canada and Mexico and South America. And you can see that these American Continents ride on the America plate. This area is the basin of the Pacific Ocean and, of course, it's called the Pacific plate. The San Andreas Fault is the boundary between the North American and the Pacific plates along the western margin of North America.

And we know from direct measurement that the Pacific plate is moving at a few inches a year relative to the America plate. In other words, Los Angeles, which is on the Pacific plates actually is moving toward San Francisco at the rate of a few inches a year and, in time, Los Angeles will be carried to the Northwest where it will join Alaska and be carried back into the interior of the earth.

Mr. GORE. That will cause quite a redistricting problem. [Laughter.]

Dr. HAMILTON. Yes, it will.

Now, the important thing to understand is that we—with this plate tectonic model—we can understand Western earthquakes in terms of these overall plate movements. But you can see that all of the Eastern United States lies within the American plate, and the movements within this plate are much less well understood, although we are making very substantial progress.

So, in the East, we are dealing primarily with intraplate earthquakes. We are trying to understand the deformations that occur within a plate rather than the deformations that occur between plates.

[Poster shown.]

Dr. HAMILTON. We've referred often to the New Madrid region and—but we haven't seen exactly where it is. This is the bootheel of Missouri and, of course, western Tennessee and northeast Arkansas, Kentucky and Illinois. The New Madrid seismic zone runs in a northeasterly/southwesterly direction through the junction of these States. The largest earthquake occurred generally in this area through northeastern Arkansas and up into the bootheel and northwestern Tennessee.

Incidentally, in field work down in this area, I've learned that the people in this part of the State like to refer to this as the Great Northwest. They told us that over and over again when we were down there.

Here's the Realfoot Lake area, which was—the lake was greatly affected by the 1811-12 earthquakes.

Mr. GORE. It was created by the—

Dr. HAMILTON. Actually, the lake existed to some extent before the earthquakes, but it was enlarged as a result of the earthquakes.

Mr. GORE. OK.

Dr. HAMILTON. And these trees are now out in the water as a result of the earthquake.

Fifteen years ago, we had no understanding at all of the origin of the earthquake activity in the New Madrid area. But as a result of studies carried out through St. Louis University and other universities in this area, and the work of Arch Johnston, and the work of the USGS and the Nuclear Regulatory Commission, we have now defined a rift zone, that is, a section of the Earth's crust that is stretched, thereby rifting it.

There's a section—there's a rift that runs through this area that has been active for hundreds of millions of years. The oldest movement in this rift occurred a few hundred million years ago, and the rift has been reactivated time and time again through history.

Mr. GORE. Dr. Hamilton, we're going to have to go over for a vote.

Dr. HAMILTON. OK.

Mr. GORE. If you—again, I apologize this has been stretched out. We've got a vote on the Pershing II missile, and we'll recess for about just 7 or 8 minutes and come back.

Dr. HAMILTON. Fine.

[Recess.]

Mr. GORE. We'll come back to order. Again, my apologies. Please proceed with your charts, Dr. Hamilton.

Dr. HAMILTON. OK, Mr. Chairman. I have only one more chart, then I'll finish up.

[Poster shown.]

Dr. HAMILTON. This figure shows a cross-section through the Earth from the surface of the Earth down to a depth of about 7½ miles. This was acquired using seismic reflection technology which is used in the oil industry to explore for petroleum deposits.

What you see here is that the upper half mile of the Earth in the New Madrid is filled with the soft sediments that fill the Mississippi Valley. For example, this is mostly mud and unconsolidated, or poorly consolidated, sedimentary deposits that fill the Mississippi Valley.

Mr. GORE. How deep is that?

Dr. HAMILTON. This goes down to about a half a mile deep.

Now, the rocks that occur below this are the same rocks that you see as you drive south from St. Louis along I-55. All the rocks that outcrop there are buried underneath this sedimentary deposit down to a couple miles deep in the New Madrid area. Further down, these rocks are the old rocks of the continent, rocks that are probably a billion years old.

OK. Now what you see as you come into the New Madrid Fault zone is you see that these rocks, which, out here, over in eastern Arkansas and western Tennessee are flat lying, that these rocks that come into the New Madrid zone are bent upward. And then, within the New Madrid zone, it appears that there are a lot of fractures and a lot of deformation. And similarly, as you come in from the West, these flat-lying rocks are bent upward.

So, at one time, these rocks were arched up into a dome or a big arch structure that was perhaps 2 or 3 miles high. So this is really a major deformational feature in geologic terms.

We think that this had a lot to do with the development of the whole Mississippi Valley, the rifting in that area. We think it's associated with volcanic activity. There's evidence that there are intrusive volcanic bodies that come up into this fault zone. This just illustrates how one might possibly be emplaced in this zone of deformation.

So in the last 15 years, we have come from a situation of not really having any good idea about the cause of New Madrid seismicity, now to understanding it fairly thoroughly in terms of the seismicity's association with geologic structure.

What we need to do in the East is achieve this understanding in more areas.

Thank you very much.

[The prepared statement of Dr. Hamilton follows:]

STATEMENT OF ROBERT M. HAMILTON, CHIEF GEOLOGIST
U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR
BEFORE THE
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT
AND
SUBCOMMITTEE ON SCIENCE, RESEARCH, AND TECHNOLOGY
MAY 23, 1984

INTRODUCTION

Mr. Chairman, I am pleased to be here today to discuss the U.S. Geological Survey's program on Eastern United States earthquakes.

EXTENT AND NATURE OF THE EARTHQUAKE PROBLEM

Although not as common as in the Western United States, moderately damaging earthquakes occur about every 20 years in the East. (When seismologists speak of the Eastern United States they generally mean those regions east of the Rocky Mountains). While the risk of damage from earthquakes is lower in the East than in Western United States, it is indeed significant. Seismic and demographic characteristics of the East increase the earthquake risk in the following ways:

- o First, the lower attenuation of seismic waves in the East causes shaking to extend over much larger areas for earthquakes of comparable magnitude.

- o Second, the high population density in the East means a large number of people are exposed to danger should a major earthquake occur.
- o Third, buildings are generally designed to a lower seismic value and earthquake preparedness is not generally pursued in the Eastern U.S.

Some of the largest earthquakes in the history of the United States have occurred in the Eastern United States. The devastating earthquakes near New Madrid, Missouri in the Mississippi Valley in 1811-12, and at Charleston, South Carolina in 1886 caused significant structural damage and ground failure and were felt throughout most of the eastern half of the Nation. Smaller but still damaging earthquakes have occurred at Cape Ann, Massachusetts; Attica, Messina, Blue Mountain Lakes, and New York City, New York; Anna, Ohio; Wilkes-Barre, Pennsylvania; and Giles County, Virginia.

The determination of the geologic structures and conditions that result in earthquakes in the Eastern United States is a complex problem. More than 90% of the seismicity of the Earth occurs along crustal plate boundaries. Geologists divide the crust of the Earth into eight or so sections or plates that drift slowly and independently over the deeper mantle. Where the boundaries of these plates meet they grind together and cause most of the earthquakes observed today. The San Andreas fault in California is a boundary between the Pacific and North American plate. As is typical of plate boundaries, the seismicity along the San Andreas shows a consistent linear pattern extending for hundreds of miles (kilometers).

The Eastern United States lies within the North American plate, the nearest plate boundaries being the San Andreas fault in California and the mid-Atlantic ridge. Earthquakes within plates, or intraplate earthquake, are poorly understood. Many do

not fall in narrow well-defined zones that show consistent patterns, but are scattered over broad regions with no obvious relationships to mapped geologic structures. The faults that cause current intraplate seismicity may be buried beneath thick sequences of younger sediments and be of limited geographic extent, thus making them difficult to map. The infrequent earthquake activity in the Eastern U.S. also makes it difficult to establish seismicity patterns and to associate the patterns with active faults. These considerations give rise to large uncertainties in defining the earthquake potential and hazards of intraplate regions. Nevertheless, a decade of data from regional seismic networks and evidence gathered in geological and geophysical investigations have resulted in significant progress in our understanding of the character and causes of some Eastern U.S. earthquakes. This progress has been appreciable in the central Mississippi Valley where seismic patterns have been defined and the structures believed to have produced the great 1811-12 New Madrid earthquakes have been identified.

The magnitude 4.1 earthquake that occurred south of Lancaster, Pennsylvania on April 22, 1984 was typical of intraplate seismicity. Low-magnitude earthquakes of this type occur throughout the East and do not appear to be a part of a recognizable pattern or to reflect a significant change in the overall rate of seismic activity. These small earthquakes are important, however, because they provide new information on the type of faulting and the basic seismic characteristics of the region.

PROGRAM GOALS

There are no easy solutions in dealing with the earthquake threat to the Eastern United States. Important questions to be answered are:

- o What is the relationship between the earthquakes and geologic structures? (i.e. what geologic structures and conditions cause earthquakes?)
- o Where are these structures and how often will large damaging earthquakes occur?
- o What is the relationship between the state-of-stress, rate of deformation, and earthquake potential?
- o Are earthquake ground motions that have been recorded in the Western United States similar to those that may be expected in the Eastern United States?
- o How do earthquake effects, such as strong ground shaking and landslides, correlate with local geology?
- o Can probabilistic procedures be used to model the earthquake ground-shaking hazard in the East?

Answers to these questions will resolve many of the uncertainties regarding the causes and effects of Eastern United States earthquakes and will provide the information necessary for effective mitigation procedures.

PROGRAM INVESTIGATIONS

The United States Geological Survey has actively participated in the study of Eastern U.S. earthquakes since the late 1800's and early 1900's when scientists investigated the 1886 Charleston, South Carolina, earthquake immediately after it occurred and the historical and geological evidence of the earlier 1811-12 New Madrid earthquakes. More recently, integrated geological, geophysical, and seismological studies have provided important new data on the nature of many Eastern

U.S. earthquakes. These investigations are being conducted by the Survey's scientific staff and by academic researchers and consultants supported by contracts.

Investigations currently or recently supported include:

- o support of seismic networks in the central Mississippi Valley, the Northeast, and the Southeast.
- o collection of magnetic and gravity data to define local and regional structure.
- o geologic mapping and drilling to locate active faults, characterize current and past surface deformation and liquefaction occurrence.
- o exploratory trenching to identify active faults and determine earthquake recurrence rates.
- o seismic reflection and refraction profiling to identify subsurface structures and to determine the geologic evolution of seismically active areas.
- o the deployment of portable arrays of seismometers and accelerometers following moderate-size earthquakes to determine seismic source parameters and to establish the character of the strong ground motion hazard.

PROGRAM ACCOMPLISHMENTS

The most significant advancements that we have made in understanding Eastern U.S. earthquakes have been in the central Mississippi Valley where the major structures have been identified that probably produced the 1811-12 New Madrid earthquakes and that are associated with most of the seismicity occurring there today. We have learned that the earthquakes in this area are associated with a zone of faults that

lies along a large buried trough, known as a rift. These faults originated millions of years ago but have been reactivated to produce the earthquakes occurring today. We have estimated from geologic and seismologic studies that large damaging earthquakes in the New Madrid area occur about every 600 years. Smaller, but still damaging earthquakes, take place about every 90-100 years. Studies have also been completed that define the extent and potential of damaging liquefaction and landslides produced by large earthquakes in the New Madrid area. The results of many of these studies have been reported in USGS Professional Paper 1236.

Our understanding of the nature and cause of East Coast earthquakes is much less definitive than for those in the Mississippi Valley. Investigations in the area of the 1886 Charleston, South Carolina, earthquake allow several different interpretations of the cause for this event. Many East Coast earthquakes appear to be associated with buried, basin-bounding faults that have very slow average rates of movement and which consequently are extremely difficult to identify. Nevertheless, encouraging progress has been made in understanding the structures associated with earthquakes in other eastern areas such as Giles County, Virginia, where a damaging earthquake occurred in 1897, and southeastern New York and northeastern New Jersey, which experiences a number of small-to-moderate-sized earthquakes annually. Geological discoveries made recently in the vicinity of Charleston, South Carolina have uncovered earthquake features that appear to show evidence of at least two large earthquakes in the region in the recent past. These discoveries would indicate that the Charleston earthquake of 1886 was not a unique event for the region. The results of many of the Survey's investigations in the Charleston area, made with significant support from the Nuclear Regulatory Commission, have been published in USGS Professional Papers 1028 and 1313.

MITIGATING THE EFFECTS OF EASTERN U.S. EARTHQUAKES

One of the most important tasks in reducing loss of life and damage to property by earthquakes is the communication of earthquake hazard information to responsible officials and interested parties. Despite our imperfect knowledge of the causes of seismicity in the Eastern United States, we have made a strong effort to communicate what we do know to state and local officials. Our approach has been to present a series of workshops that bring together the producers and the users of earthquake hazard information with the goal being that of implementing research results by local governments, engineers, architects, and emergency services planners. Support for these workshops has been shared at times by the Federal Emergency Management Agency, the National Science Foundation, the Nuclear Regulatory Commission, and the National Bureau of Standards. Nevertheless, the USGS plans, conducts, and reports the results of these workshops, and thus we take considerable pride in this strong initiative in research utilization.

The first of the series of workshops in the East was held in Knoxville, Tennessee, in September 1981 and demonstrated that policymakers and members of the scientific-engineering community can assimilate a great deal of technical information about earthquake hazards and work together to devise practical mitigation plans. The workshop resulted in the creation of a draft 5-year work plan to improve the state-of-earthquake-preparedness in the Eastern United States and marked the birth of the South Carolina Seismic Safety Consortium. A second workshop was held in St. Louis, Missouri, in May 1982, which resulted in the identification of specific actions to reduce losses that could be implemented immediately and in the formation of the Kentucky Task Force on Earthquake Hazards and Safety. A third workshop was held in Charleston, South Carolina in May 1983, and had multiple objectives involving the

discussion of scientific information and its use in earthquake preparedness and the siting of critical facilities. A fourth workshop was held at Massachusetts Institute of Technology, Cambridge, Massachusetts, in June 1983, and was designed to define the earthquake threat in the northeastern United States. A fifth workshop was held in Little Rock, Arkansas, in September, 1983 and was designed to accelerate the ongoing work of the Arkansas Office of Emergency Services, providing a forum for discussion of their activities to prepare for and respond to the earthquake hazard in that region.

CONCLUSION

Although significant scientific problems remain, important progress has been made in determining the causes of Eastern U.S. earthquakes and in disseminating information to the public. We shall continue our efforts and as additional scientific data are obtained, we look forward to further progress in reducing earthquake hazards in the East. I would be happy to answer any questions you may have.

Mr. GORE. OK. Thank you very much for very interesting testimony.

We will now have our last witness, Mr. Robert Minogue. Am I pronouncing your name right?

Mr. MINOGUE. Yes, sir, that's exactly correct.

Mr. GORE. Good. Director of the Office of Nuclear Regulatory Research at the Nuclear Regulatory Commission.

Mr. Minogue, we are delighted to have you here and, if you could summarize your prepared statement, we'd appreciate it.

Mr. MINOGUE. Thank you, Mr. Chairman. I will summarize it.

I intend to discuss the Nuclear Regulatory Commission's Seismic Research Program in the Eastern United States, how it supports the Commission's regulatory mission, and how it relates to the overall seismic hazard assessment for the United States east of the Rocky Mountains.

Among severe natural phenomena, earthquakes present the greatest hazard to nuclear powerplants. All nuclear powerplants are designed to be capable of safe shutdown to specific levels of earthquake ground motion. Earthquakes can be an important source of common mode failure, and proper consideration of earthquake hazard in nuclear powerplant design is important to nuclear safety. In addition, nuclear powerplant safety has imposed requirements heretofore unknown in more conventional earthquake engineering. Specifically, large containment buildings must remain essentially leaktight after severe ground shaking, and mechanical and electrical systems needed to shut down the reactor and remove decay heat must remain functional during and after large earthquakes.

Conventional earthquake engineering practice does not provide in itself an adequate level of safety for nuclear powerplants. Nuclear powerplants are required to be sited, designed and regulated using advanced earthquake engineering concepts, and successful implementation of these highly sophisticated concepts requires that the best information about earthquake levels for the site of the plants be obtained, including a good characterization of the seismic hazard.

The lack of total understanding of the causative mechanisms of the Eastern United States earthquakes and the observation that the potentially seismogenic structures are generally buried beneath from one meter to tens of kilometers of sediments make it difficult to define the seismic hazard in unequivocal terms.

The applicants for nuclear powerplant licenses provide basic geoscientific data for the area in the immediate vicinity of the plant sites, and a number of State, Federal and private organizations are satisfying local data requirements. However, the broad regional perspective for earthquake hazard in the Eastern United States was not being developed as rapidly as needed for NRC decisionmaking. Thus, to meet its statutory requirements to regulate nuclear powerplants in a manner that will protect the public health and safety, the NRC undertook the research necessary to accelerate the development of the needed seismic hazard information base.

That need is being fulfilled by the NRC Seismotectonic Research Program, which is divided into two segments. The first is a regional program which provides basic seismological and geological information about the occurrence of earthquakes in the Eastern United States; and the second provides techniques for estimating and dealing with the existing uncertainty in the basic data set.

An important element in this second segment of our research program is a major research project which is being conducted at Lawrence Livermore National Laboratory. In this project, a probabilistic technique is being developed to calculate seismic hazard for any nuclear powerplant site in the Eastern United States. This technique makes significant use of expert seismological opinion about seismic zonation, seismicity, recurrence rates, and attenuation with distance.

The first segment, the regional program of our research program, will be the subject of the remainder of my testimony. There are four geographic regions being covered by our regional program. They are the Northeastern United States, the Southeastern United States, the New Madrid region and the Nemaha Ridge region.

In each of these geographic regions, the NRC provides the principal support for the operation of seismographic networks and conducts related geological and geophysical investigations of the areas of active seismicity. I am providing for the record maps of the networks, a list of the contractors, and a more detailed summary of the seismotectonic research plan, a summary which was prepared late last year.

In the approximately 5 years to date in which these seismographic networks have operated, we have obtained a considerable amount of information on earthquakes in the Eastern United States. But there is much more to be learned, and a significant

level of uncertainty remains about seismological issues which must be reduced. Some of the unresolved seismic hazard issues include possible correlations of seismicity with tectonic structures, propagation of seismic strong motion and ground motion—strong ground motion with distance, and the character of earthquake sources in the Eastern United States.

The issue of seismic hazard in the Eastern United States is a national issue affecting the programs and missions of many Federal and State agencies. It is appropriate that a Federal agency with specific expertise and talent in this area of geology and seismology play a very active lead in the Eastern United States. This is not to imply that significant infusions of money are required, but that a concerted effort is required to pool the existing funds to carry out a more efficient program. In addition, there are a good number of Federal, State, and private agencies with a significant interest in this program who are not contributing financially to the solution.

The NRC has recognized a critical need for improved assessment of the earthquake hazard in the Eastern United States in order to accomplish its mission. A program was developed and has been implemented, and it is currently satisfying our needs, but it represents a significant resource drain in an area removed from our principal mission. It seems inappropriate for the NRC to be a lead funding agency in eastern seismological research. We hope that a specific coordinated working group of interested agencies can be formed around the nucleus of the four agencies cited by the National Earthquake Hazard Reduction Act to further address the earthquake hazard issue in the East. We see our role in such a group as that of an important contributor with an influential, but not controlling, role.

Mr. Chairman, in the text of my prepared testimony and in the attachments, I dealt with the seismological and geological research program that we have.

I should mention, in view of some of the discussion that's gone before, that we also have an engineering design program which concentrates primarily on development of analytical methods to look at the complex nuclear plant system response. That work is closely coordinated with work by the Electric Power Research Institute, and also with some very large programs that are being done in other countries, particularly in Japan and in Germany, where very large amounts of money are being spent both in developing analytical methods and also in validating those methods by experimental work.

Thank you, Mr. Chairman.

[The prepared statement, plus attachments of Mr. Minogue follow:]

TESTIMONY OF ROBERT B. MINOGUE
DIRECTOR, OFFICE OF NUCLEAR REGULATORY RESEARCH
U. S. NUCLEAR REGULATORY COMMISSION
BEFORE THE
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY
AND THE
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT
OF THE
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
MAY 23, 1984

Chairman:

My name is Robert Minogue. I am the Director of the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research. I am pleased to appear before these Subcommittees to discuss the Commission's seismic research program in the Eastern United States, how it supports the Commission's regulatory mission and how it relates to the overall seismic hazard assessment for the United States east of the Rocky Mountains.

Among severe natural phenomena, earthquakes present the greatest hazard to nuclear power plants. All nuclear power plants are designed to be capable of safe shutdown to specific levels of earthquake ground motion, the earthquakes which are used as a basis for design. However, earthquakes beyond the design basis could cause complex multiple failures that might lead to transients and operating conditions not anticipated by the designers. Thus, earthquakes can be an important source of common mode failure, and proper consideration of earthquake hazard in nuclear power plant design is important to nuclear safety. In addition, nuclear power plant safety has imposed requirements heretofore unknown in more conventional earthquake engineering. Specifically, large containment buildings must remain essentially leaktight after severe ground shaking, and mechanical and electrical systems needed to shut down the reactor and remove decay heat must remain functional during and after large earthquakes.

Studies completed in the United States that attempt to understand the complex interactions among structures, systems and components have indicated that earthquakes beyond the design basis earthquake can be a large contributor to the total risk associated with nuclear power plants. This is true in the Eastern United States, which is less prone to earthquakes than is California. Conventional earthquake engineering practice for ordinary buildings and structures does not provide in itself an adequate level of safety for nuclear power plants. Most ordinary structures are designed on an implicit two tier system in that in the event of a small or moderate earthquake emphasis is on the functional integrity of the structure, while in event of a large earthquake, emphasis is shifted to preventing serious personal injury. Thus, in conventional earthquake engineering practice when confronted by a large earthquake, little emphasis in design considerations is placed on continued operation of equipment within structures. Designers and owners of nuclear power plants, and the U.S. NRC as regulators of these facilities, are required to site, design, and regulate facilities using advanced earthquake engineering concepts. Successful implementation of these highly sophisticated concepts requires that the best information about the earthquake levels for the site of the plants be obtained.

The NRC has a continuing requirement for sound technical bases for its review and evaluation of submittals from license applicants. This requirement includes a need to better define and understand the seismic hazard in the Eastern United States; i.e., for scientific purposes that portion of the country east of the foothills of the Rocky Mountains. The lack of total understanding of the causative mechanisms of Eastern United States earthquakes and the observation that the potentially seismogenic structures are generally buried beneath from one meter to tens of kilometers of sediments make it difficult to define the seismic hazard in unequivocal terms.

The applicants for nuclear power plant licenses provide basic geoscientific data for the area in the immediate vicinity of the plant sites and a number of state, Federal and private organizations are satisfying local data requirements. However, the broad regional perspective for earthquake hazard

assessment in the Eastern United States was not being developed as rapidly as needed for NRC decision making. Thus, to meet its statutory requirements to regulate nuclear power plants in a manner that will protect the public health and safety, the NRC undertook the research necessary to accelerate the development of the needed seismic hazard information base.

The need for an information base in the Eastern United States is being fulfilled by the NRC Seismotectonic Research Program. The NRC Seismotectonic Research Program can be divided into two segments. The first is a regional program which provides basic seismological and geological information about the occurrence of earthquakes in the Eastern United States and the second provides techniques for estimating and dealing with the existing uncertainty in the basic data set.

An important element of this second segment of the NRC Seismotectonic Research Program is a major research project being conducted at Lawrence Livermore National Laboratory. In this project a probabilistic technique is being developed to calculate seismic hazard for any nuclear power plant site in the Eastern United States. This technique makes significant use of expert seismological opinion about seismic zonation, seismicity, recurrence rates, and attenuation with distance. It will be used by the licensing staff to screen all existing nuclear power plants in the East for potentially difficult sites.

The first segment or regional program of the NRC Seismotectonic Research Program will be the subject of the remainder of my testimony. There are four geographic regions being covered by our regional program. They are the Northeastern United States, the Southeastern United States, the New Madrid Region, and the Nemaha Ridge Region. As progress has been made in the program, the principal emphasis has shifted. Prior to 1981, the program was reasonably broad based covering many different aspects of the Eastern United States seismic hazard problem confronting the NRC. After that date, because of the significant information accumulated by the NRC, utility applicants and other agencies, the NRC has been able to narrow the scope of its research to more specific problems and problem areas.

In each of these geographic regions the NRC provides the principal support for the operation of seismographic networks and conducts related geological and geophysical investigations of the areas of active seismicity such as seismic reflection profiles across the Ramapo Fault System and the Central Virginia Seismic Zone and deep stress measurements near Moodus, Connecticut. (I am providing for the record maps of the networks, a list of contractors, and a more detailed summary of our Seismotectonic Research Plan.)

The approximately five years to date of seismographic network operation have provided a considerable amount of information on earthquakes in the Eastern United States such as epicentral locations and magnitude distributions, but there is much more to be learned and a significant level of uncertainty about seismological issues to be reduced. To perform its regulatory function, the NRC needs additional information and has to continue its seismological and geological research. Some of the unresolved seismic hazard issues include: possible correlations of seismicity with tectonic structures, propagation of seismic strong-ground motion with distance, and the character of earthquake sources in the Eastern United States.

The issue of seismic hazard in the Eastern United States is a national issue affecting the programs and missions of many Federal and state agencies. It is appropriate that a Federal agency with specific expertise and talent in this area (seismology/geology) play a very active lead in the Eastern United States. This is not to imply that significant infusions of money are required but that a concerted effort is required to pool the existing funds to carry out a more efficient program. In addition, there are a good number of Federal state and private agencies with a significant interest in this program who are not contributing financially to the solution.

The NRC has recognized a critical need for improved assessment of the earthquake hazard in the Eastern United States. A program was developed and has been implemented; it is currently satisfying our needs but represents a significant resource drain in an area removed from our principal mission. It seems inappropriate for the NRC to be a lead funding agency in eastern

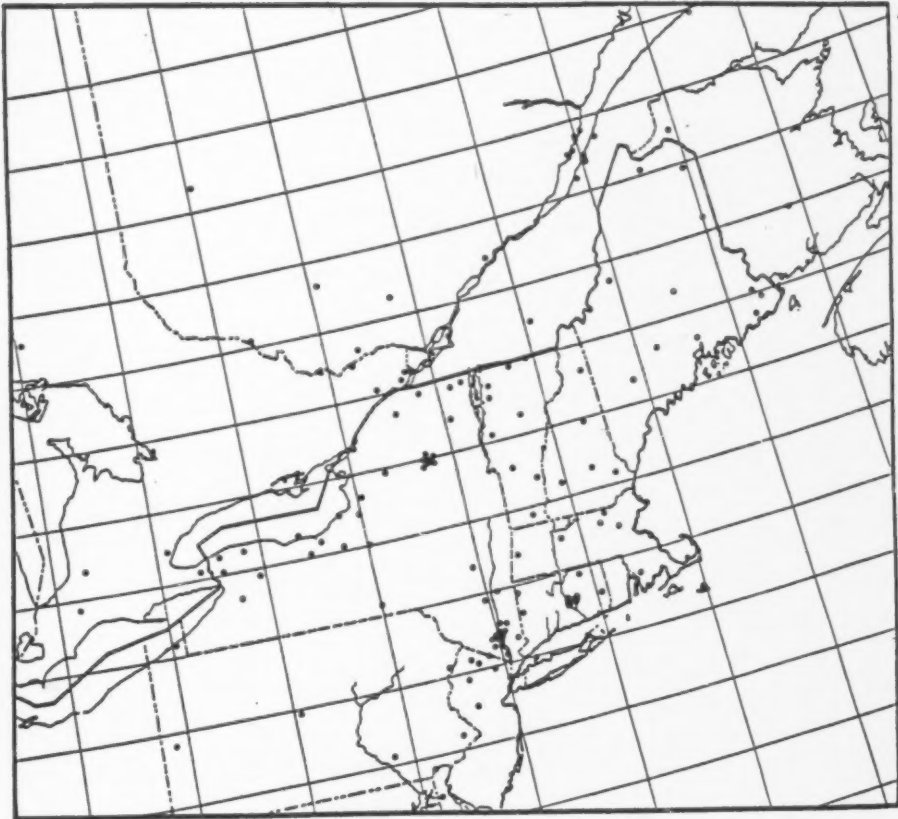
seismological research. We hope that a specific coordinated working group of interested agencies can be formed around the nucleus of the four agencies cited by the National Earthquake Hazard Reduction Act (FEMA, USGS, NSF, and NBS) to further address the earthquake hazard issue in the East. We see our role in such a group as an important contributor with an influential but not controlling role.

List of Attachments:

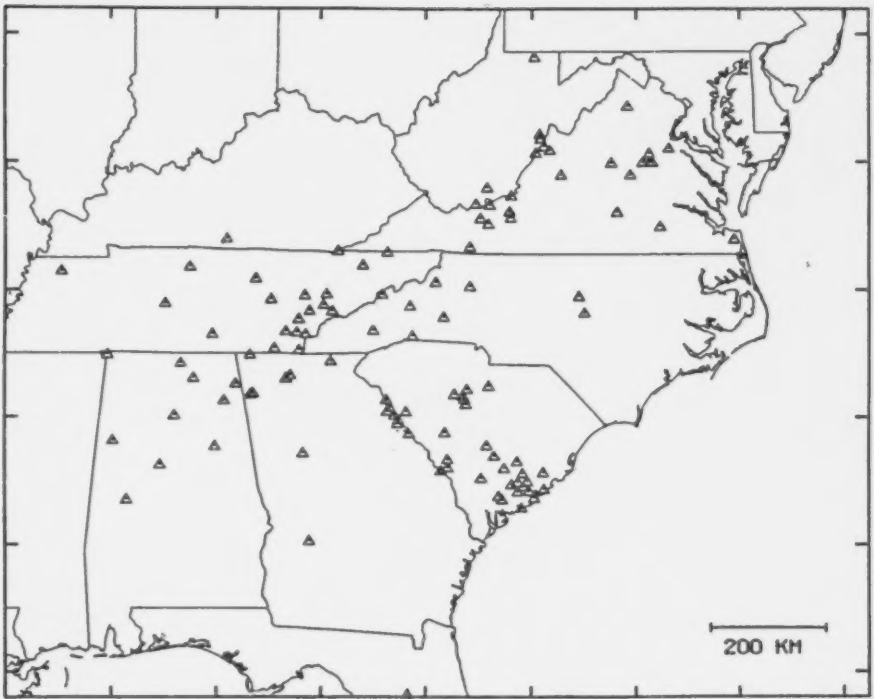
1. Maps of the four regional seismographic networks
2. List of the NRC contractors for the regional networks
3. The RES Seismotectonic Research Plan II

ATTACHMENT #1

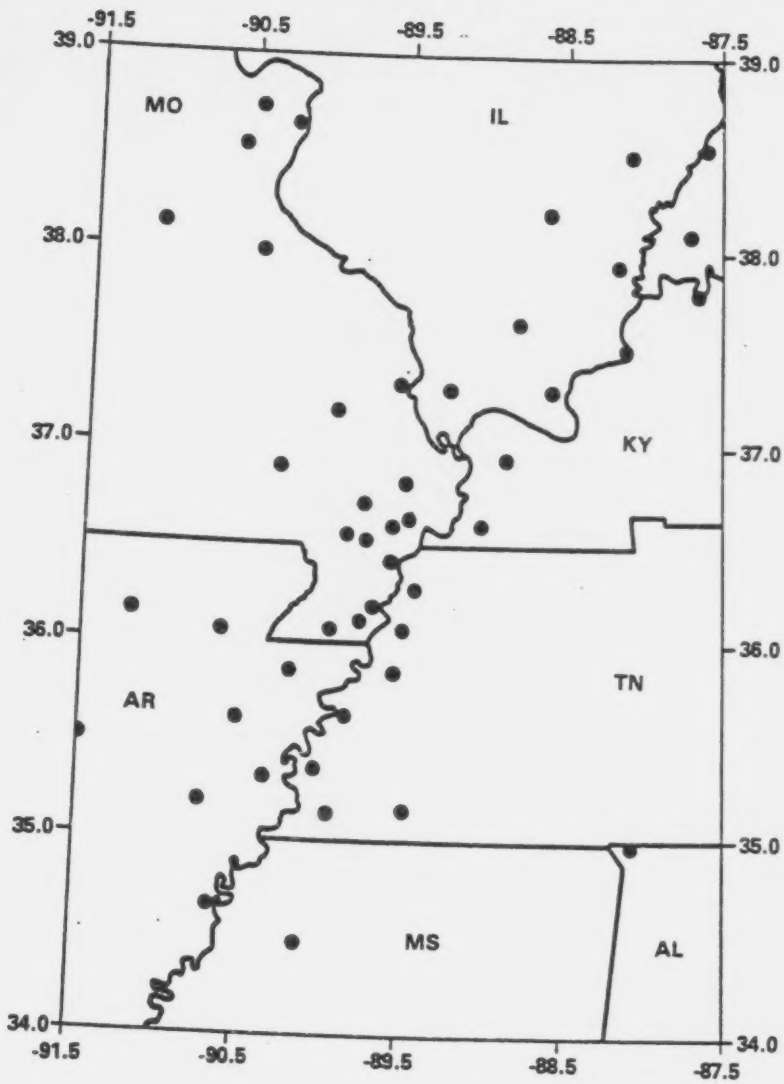
MAPS OF THE FOUR REGIONAL SEISMOGRAPHIC NETWORKS



MAP 1 SEISMIC STATIONS OF THE NORTHEASTERN
UNITED STATES SEISMOGRAPHIC NETWORK



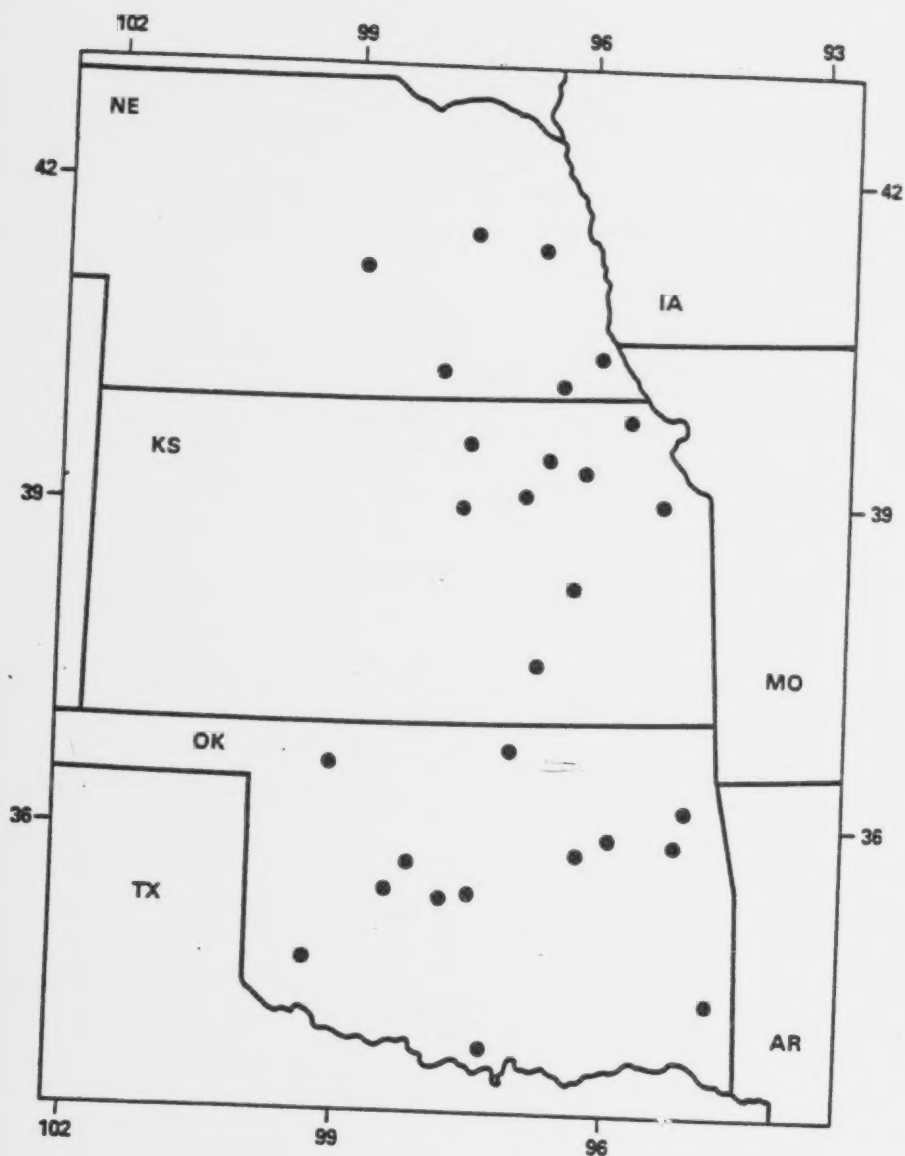
MAP 2 SEISMIC STATIONS OF THE SOUTHEASTERN
UNITED STATES SEISMOGRAPHIC NETWORK



MAP 3A SEISMIC STATIONS OF THE CENTRAL PORTION OF THE NEW MADRID REGIONAL SEISMOGRAPHIC NETWORK



MAP 3B SEISMIC STATIONS OF THE NORTHEASTERN
ARM OF THE NEW MADRID REGIONAL
SEISMOGRAPHIC NETWORK



MAP 4 SEISMIC STATIONS OF THE NEMAHA RIDGE REGIONAL SEISMOGRAPHIC NETWORK

ATTACHMENT #2

LIST OF THE NRC CONTRACTORS FOR THE REGIONAL NETWORKS

SEISMIC NETWORKS FUNDED BY ESB - RES

Al. Geol. Surv. - SE Tenn. - N. Alabama Networks
Boston College - New England Networks
CC Corp. - Canadian Seismic Coop. Study Network
Columbia U. - NY and Adjacent areas Networks
MIT - Seismicity study - Mass. New H. Networks
MSU - Southern New Madrid Network
MSU - E. Tenn Regional Seismic Network
Penn State U. - Pa. Seismic Network
RFP - MIT, Bost. Coll. - NE Seismographic Networks
St. Louis U. - New Madrid Research Program Network
SUNY - Long Island Seismic Network
U. Kansas - Nemaha Ridge Seism. Network
U. Michigan - Ohio/Indiana Seism. Networks
U. Oklahoma - Nemaha Ridge Seism. Network
U. Washington - Oregon and Washington Network
USAF - Broad Band Seismic Data Anal. Long Island experimental Network
VPI - Central Va. Seismicity Network
USGS - Charleston SC Network

ATTACHMENT #3

THE RES SEISMOTECTONIC RESEARCH PLAN II

SEISMOTECTONIC PROGRAM PLAN II

EXECUTIVE SUMMARY

Purpose

Seismic hazards are significant contributors to the overall hazard at some nuclear power plants. Estimation of these hazards is a very significant factor in siting of nuclear power plants and evaluating the safety of existing power plants. There is considerable uncertainty in estimating the seismic hazard particularly in the Eastern United States. The objectives of the Earth Sciences Branch (ESB) seismotectonic research are to quantify and reduce the uncertainty in seismic hazard assessment and to develop methods of dealing with uncertainties. The purpose of the Seismotectonic Program Plan (STPP) is to describe (1) the technical and regulatory issues generated by the uncertainty in seismic hazard assessment, (2) the ESB research program designed to address the issues, and (3) the relationship of the ESB research to other research programs within NRC, within other government agencies, and in the private sector.

Issues

The fundamental regulatory issue addressed by STPP is the seismic hazard assessments used in estimating seismic risk to nuclear power plants. This issue is specifically addressed by confirmatory research in support of the data and analysis techniques used for licensing decisions and by research in support of regulatory guidance and possible revision of the current regulation, Appendix A to 10 CFR Part 100.

The recent (November 1982) U.S. Geological Survey (USGS) clarification of its position on the 1886 Charleston earthquake raised a regulatory issue that needs a timely response. The USGS notes that it has not been able to associate the Charleston earthquake with a geologic structure and that there is a probability, albeit very low, that the level of ground motion associated with a Charleston-sized earthquake could occur elsewhere on the eastern seaboard. This presents a problem. Under existing seismic siting criteria, Appendix A to 10 CFR 100, the ground motions produced by an earthquake not associated with

a specific structure are postulated to occur at any location in the tectonic province within which it occurred. If a nuclear power plant is within that tectonic province the earthquake is postulated to occur near the plant site. If the plant is in a different province, the ground motions at the site are calculated as if the earthquake occurred on the point on the province boundary closest to the plant.

If the 1886 Charleston earthquake cannot be correlated with a structure, it could be considered to occur anywhere within the tectonic province. Because the tectonic provinces in the East are large, this could result in the postulation of ground motions as large as those of the Charleston earthquake at almost every reactor site in the eastern seaboard. This could have very serious implications for the licensing process.

The Geosciences Branch, NRR, has developed an interim licensing position and an action plan to address the Charleston issue. The action plan has been transmitted to the Division of Health Siting and Waste Management (DHSWM) via a memorandum dated March 22, 1983 from Vollmer to Arsenault with a response dated May 20, 1983.

Program Plan

Three issues contribute to the uncertainty in seismic hazard assessment; the program plan is organized around them. Those issues are (1) the uncertainty in establishing seismic source zones, (2) the uncertainty in the propagation of seismic energy, and (3) the uncertainty in the site specific ground motion response of the site including soil failure. The program consists of three parts: regional programs that address the uncertainty in seismic source zone configurations and seismic energy propagation; topical programs that deal with developing site specific spectra, strong ground motion models, and soil failure models; and probabilistic programs that deal with techniques to handle the uncertainties.

The regional program consists of seismological and geologic/geophysical programs in the Southeast, the Northeast, the New Madrid/Anna, Ohio area, the Nemaha Uplift area, and the Pacific Northwest. The results from the seismic

networks help define the zones of active seismicity and the basic seismological parameters of that activity. The geologic/geophysical investigations attempt to verify the proposed seismic zonations and seismogenic mechanisms. This is necessary because of the short seismic history in the United States.

The topical programs include analysis of strong motion data from the eastern U.S. and analysis of seismic energy propagation. Validation of soil failure models and the feasibility of utilizing data from underground nuclear explosions will be examined. The probabilistic programs include a study of the sensitivity of predicted seismic ground motion to variations in models of seismic source zones. A previous study utilizing expert opinion is now being improved and expanded for use in the resolution of the Charleston problem.

CONTENTSINTRODUCTION1 TECHNICAL ISSUES1.1 Hazard Uncertainties1.1.1 Regional Issues

- 1.1.1.1 Southeastern United States
- 1.1.1.2 Northeastern United States
- 1.1.1.3 New Madrid Region
- 1.1.1.4 Nemaha Region
- 1.1.1.5 Pacific Northwest Region

1.1.2 Topical Issues

- 1.1.2.1 Source Parameters
- 1.1.2.2 Propagation/Attenuation Characteristics
- 1.1.2.3 Site Response Characteristics
- 1.1.2.4 Soil Failure

1.2 Handling Uncertainties2 PROGRAM PLAN2.1 Estimation and Reduction of Uncertainty2.1.1 Regional Programs

- 2.1.1.1 Southeastern United States
- 2.1.1.2 Northeastern United States
- 2.1.1.3 New Madrid Region
- 2.1.1.4 Nemaha Region
- 2.1.1.5 Pacific Northwest Region

2.1.2 Topical Programs

- 2.1.2.1 Source Parameters
- 2.1.2.2 Propagation/Attenuation Characteristics
- 2.1.2.3 Site Response Characteristics
- 2.1.2.4 Soil Failure

2.2 Program to Address Uncertainties

- 2.2.1 Seismic Hazard Characterization of the Eastern United States
- 2.2.2 Earthquake Recurrence Intervals for Nuclear Power Plants
- 2.2.3 Selection of Earthquake-Resistant Design Criteria for Nuclear Power Plants; Methodology and Technical Bases
- 2.2.4 Site-Specific Response Program

CONTENTS (Continued)

3 RELATION OF STPP TO OTHER PROGRAMS3.1 NRC Seismic Research

- 3.1.1 RES
- 3.1.2 NRR
- 3.1.3 NMSS

3.2 Other Government Agencies

- 3.2.1 FEMA and the NEHRP
- 3.2.2 USGS
- 3.2.3 NSF
- 3.2.4 Corp of Engineers
- 3.2.5 Veterans Administration
- 3.2.6 State Agencies

3.3 Private Sector ResearchAppendices

- Appendix A Budget
- Appendix B National Center For Seismological Studies
- Appendix C Programs Elements Required to More Expeditiously Resolve Seismic Issues

INTRODUCTION

Seismic hazards are significant contributors to the overall hazard to some nuclear power plants. Research directed at estimating and reducing the uncertainty in the seismic hazard and research directed at coping with the uncertainty are central themes of the Seismotectonic Program Plan II (STPP). It is an Earth Sciences Branch (ESB) position that the uncertainties in seismic hazard assessments are higher in the Eastern United States than in the Western United States (the eastern foothills of the Rocky Mountains constitute the dividing line). Because the majority of nuclear power plants are in the East, the ESB research is concentrated there.

Three of the principal sources of uncertainty in establishing seismic hazards in the East are uncertainties in the seismic source zones, the propagation of seismic energy, and the site response.

The Charleston 1886 earthquake is an example of how these three factors combine in the East to produce high uncertainties. The 1886 earthquake has not been associated with a structure in Charleston; thus, it might be assumed to have an equal probability of occurrence throughout the eastern seaboard. Although the Charleston earthquake was of about the same magnitude as the 1971 San Fernando Valley earthquake, the Charleston earthquake had about 10 times the area of equivalent damage. The site-specific response throughout the coastal plain is additionally complicated by the possibility of severe differential soil settlement and soil liquefaction leading to severe differential structural settlement. Thus all these factors contribute to produce an overall high uncertainty in seismic hazard estimate in the eastern seaboard.

The ESB conducts research addressing each of these sources of uncertainty and also conducts research on methods to handle or cope with the uncertainties in a regulatory environment. These projects include development of "probabilistic" techniques for estimating seismic hazard curves and recurrence information for long return periods. The increased use of probabilistic risk assessments (PRA) for analysis of nuclear power plant sites has created a need for this type of study.

Probabilistic assessment of risk requires methodologies to handle the uncertainties in seismic hazard assessments. The present licensing criteria are "deterministic", and are based on procedures in Appendix A to 10 CFR Part 100. The probability of ground shaking above the design level is not explicitly considered. However, PRAs show that a major contribution to risk is due to earthquakes several times the design level. Three approaches are presently being utilized to develop a probabilistic approach to handle the known uncertainties: expert panels, formal sensitivity studies, and examination of methods of estimating recurrence rates.

The issues in seismic hazard assessment are addressed in this document in three sections.

Section 1 - The technical issues of seismic hazard assessment.

Section 2 - ESB research program to address those issues.

Section 3 - Relationship of other research programs to ESB research programs.

1 TECHNICAL ISSUES

The three fundamental technical issues addressed by ESB seismotectonic research are how to quantify and reduce the uncertainties in seismic hazard assessments and how to develop techniques to deal with the uncertainties in a regulatory environment. These issues are closely related. The more accurately the principal contributors to the uncertainty are quantified or understood, the more precisely the contributors can be handled in a regulatory environment. These issues are discussed below in the sections 1.1, Hazard Uncertainties, and 1.2, Handling Uncertainties.

1.1 Hazard Uncertainties

As noted earlier, three of the principal contributors to the uncertainty in quantifying the seismic hazard at a site are the characteristics of the seismic source zone, the propagation of seismic energy between the source and the site, and the site response, including soil response. The relative levels of contribution of these three to uncertainty are region dependent. (For programmatic ease, the Eastern United States has been divided into four regions: Northeast, Southeast, New Madrid/Anna, Ohio, and Nemaha Ridge.) Currently, there is a reasonable level of confidence in a working hypothesis for the source of seismicity in the New Madrid area and a moderate understanding of some of the regional propagation characteristics. There are a number of hypotheses for the source of Southeastern seismicity including the Charleston, S.C., area. No generally accepted hypotheses are available for the Northeast or the Nemaha Ridge. There is a low level of knowledge about the propagation and site response characteristics in the East except as noted for the New Madrid region.

Source zone uncertainties are the most visible problems in the eastern seaboard. This was underscored by the recent United States Geological Survey (USGS) clarification of position on the Charleston 1886 earthquake. That position established the Charleston seismicity as an eastern seaboard earthquake problem. In the opinion of the USGS, there is an insufficient historical data base to establish seismic zonation on the basis of seismicity alone, and the causative mechanisms of eastern earthquakes are, with few exceptions, not known.

In areas like the Eastern United States, this inability to identify the causative mechanisms is particularly difficult to deal with; knowledge of the causative mechanisms can be used to compensate for the lack of a long historical data base by establishing source zones on the basis of geology. Studies of the Chinese data base have shown the validity of that approach, i.e., determining the causative mechanism. Unfortunately, studies of that same data base have shown that, without the causative mechanism, the 2000+ year seismic history is too short for seismic zonation if the source zones cannot be constrained on the basis of geology.

The issues are presented in two groups: regional issues, which are mainly issues of seismic source zone uncertainties, and topical issues, which are issues of seismic attenuation, site-specific spectral analysis, and soil liquefaction.

1.1.1 Regional Issues

There are four eastern regional programs and a limited regional program in the Pacific Northwest. In the regional areas there is one basic problem: what is the cause of the seismicity. The problem is fundamental to the other problem of seismic source zone uncertainties, which are where can seismicity occur, with what magnitude, and with what frequency. In some areas experts have more confidence in the seismic zonation than others. A short discussion of the source zone issues for each of the regions follows.

1.1.1.1 Southeastern United States

The Charleston 1886 earthquake dominates the seismic history of the Southeastern United States. The cause of that earthquake is not known. Numerous hypotheses have been proposed, mostly involving reactivation of older faults. Most of the hypotheses imply the possibility of Charleston-like motion elsewhere in the eastern U.S. Faults that cut Mesozoic and Cenozoic sediments have been found by seismic refraction and reflection investigations in the Charleston region. However, the faults do not cut the surface. The Cooke fault and the Helena Banks fault, both trending NE, are examples of this. The Bel Air fault near Augusta cuts Mesozoic beds and it also trends NNE. None of

these faults have been demonstrated to be seismogenic or even active in the Quaternary. There are other areas of seismicity in South Carolina in addition to the Charleston area. The relationship of that activity to Charleston activity is yet to be clearly established.

Two other areas of significant seismicity in the Southeast are the Giles County and Central Virginia seismic zones. In these areas some progress has been made toward the correlation of seismicity with structure.

Preliminary data from the Central Virginia seismic zone show the possibility of correlation of earthquake hypocentral locations and a structure defined by seismic reflection profiling. Good quality hypocentral locations are available because of the station distribution and a good velocity model of the area. Excellent information on crustal structure was available because of detailed geologic mapping, good magnetic and gravity data, and a state-of-the-art seismic reflection profile. The locations of earthquake hypocenters apparently correlate with an ESE dipping listric fault that was a splay of the decollement. No fault plane solutions are available, and consequently the sense of motion is unknown.

Recent developments on the stress field in the Southeast raised questions about the sense of motion on faults previously considered unambiguous. The Stafford fault zone of northern Virginia is a NNE trending fault zone that shows about a hundred meters of reverse motion. Previously it was considered that the direction of stress east of the Blue Ridge was NW-SE directed consistent with the reverse motion of the Stafford fault system. New data suggests a N60°E direction of the maximum compressive stress. If this direction is correct, the Stafford, Bel Aire, Cooke, and Helena Banks faults all could be primarily strike-slip faults. The observed vertical components could be secondary.

This new stress information is critical for interpreting the Central Virginia seismic zone. If the stress direction is correct, the listric splay of the Central Virginia seismic zone may be reactivated as a primarily strike slip fault, and motion along the decollement would be secondary.

The hypocenters in the Giles County seismic zone are mostly below the decollement surface. Consequently, the observable structure at the surface or in the first few kilometers are not expected to give information useful in interpreting the seismicity there. Previous hypocentral locations have delineated a source zone of the seismicity, which is proposed to be a deeply buried fault system. The existence of such a structure is consistent with the tectonics of the area. The structure could be observable by detailed seismic experiments described in Part II.

1.1.1.2 Northeastern United States

The seismic activity of January 1982 dominates the recent seismic history of the Northeast. The magnitude 5.7 and 5.0 earthquakes in New Brunswick and the magnitude 4.7 in New Hampshire supplied critical information. There are now over 15 strong motion records from those events and the aftershock sequences. Although structures are observable on the surface, no cause and effect relationship has been generally accepted. The most significant geologic development in New England since the first version of this seismotectonic plan was written is the apparent clarification of the issue of the stress direction in the New England area. The direction of maximum compressive stress throughout the region is most likely about N50°E to N80°E. This is the same as the direction in the midcontinent. Previously, it was thought to be oriented about NW-SE and it was thought to have the same orientation in the Southeast also. This new direction is supported by four different studies: a utility study of the seismicity of the Ramapo fault zone, deep hydrofracture stress measurement in New York State by Dr. Marc Zoback of the USGS, and an NRC-funded USGS investigation along the coast of Maine utilizing shallow stress measurements.

An important implication of this stress direction concerns the Ramapo fault system. There is a coincidence of seismicity with the Ramapo and other fault systems in the Highlands although the cause and effect relationship is not established. The Ramapo fault system forms the western boundary of a Triassic basin. A N50°E stress field would act on those structures to cause a strike-slip type motion. Previously, most reactivation mechanisms proposed for pre-existing faults have been gravity backsliding or reverse motion.

Seismicity and other recent crustal movements in the Passamaquoddy Bay area may be related to reactivation of the Triassic basin in the Bay of Fundy. Recent stress measurements indicate that the basin would be reactivated in oblique normal faulting. This area is important for the "Triassic Basin" hypotheses of eastern seaboard seismicity. The Bay of Fundy basin is the basin similar in both structure and dimension to the true continental rifts, such as the Rhine Rift, the Reelfoot Rift, or the East African Rift system. The Bay of Fundy basin shows a very strong magnetic signature, magnetic highs paralleling the edges, that is consistent with mantle involvement in the structure. (This is different from most Triassic basins, which are probably restricted to the crust.)

1.1.1.3 New Madrid Region

The seismogenic mechanism in the New Madrid region is best understood in the East. A zone of seismicity follows the trend of a basement rift, the Reelfoot rift system. The zone of the very severe 1811-1812 main shock sequence is centered about an offset in the rift that also is the location of a zone of uplift. The proposed seismogenic mechanism is the reactivation of the rift as a strike-slip fault zone. This is consistent with the structure, fault plane solutions, and stress measurements.

The issue that is outstanding is the extent of the seismic source zone to the North and South. The trend of the rift has been extended from the New Madrid zone up to the Anna, Ohio, earthquake zone. This trend does follow photo linears and some surface faulting trends. Seismic reflection profiling also indicate structure along the extension. However, the gravity and magnetic signatures of the rift along the proposed northern continuation are not as strong as in the segment in the Mississippi Embayment. Some short extensions of the rift are apparent to the Northwest, but if the model of rift reactivation is correct, they should not be significant seismic source zones because the stress field will not be properly oriented to reactivate the segments into a strike-slip system.

1.1.1.4 Nemaha Region

The Nemaha Uplift in the Central U.S. is associated with moderate earthquake activity. Together with the Midcontinent Geophysical Anomaly, the uplift may represent a rift zone that is accompanied by clastic filled basins on the east side, the basins being separated from the rift zone by a series of faults. The Humboldt fracture zone in Eastern Nebraska and Kansas represents such a fault that is associated with seismicity. The Thurman Redfield and Northern Boundary fault zones in Iowa have been intermittently active since Paleozoic time.

Elsewhere, the relationship between the uplift and the seismicity is not very clear. However, seismic activity is present all along the Nemaha Uplift. The activity seems to occur particularly at locations where NW trending structures or anomalies cross the Nemaha Uplift.

1.1.1.5 Pacific Northwest Region

The Pacific Northwest is a region that is a transition from the strike-slip tectonic to the south in California to the subduction zone tectonic to the north in Alaska. The regional seismicity is associated with a moribund subduction zone beneath Washington and northern Oregon. The outstanding seismic issue is the characterization of the current tectonics of the region; i.e., are the large earthquakes in the region within a subduction zone, is there a seismic gap, and what other features, including the volcanoes, are controlling the seismicity?

1.1.2 Topical Issues

There are a number of issues that are less amenable to regional characterization and are called topical. These include propagation/attenuation characteristics, soil response studies, and strong ground motion studies. They are basically ground motion issues and will be considered in this section in the direction of propagation, i.e., from source to receiver site.

1.1.2.1 Source Parameters

The issue involves the proper characterization of source parameters for Eastern U.S. earthquakes. These parameters include source spectra, dynamic and static

stress drop, duration, focal mechanism, corner frequency, moment, and magnitude. Knowledge of these parameters and how they vary with earthquake location and size is critical to understanding eastern earthquakes.

The stress drop, focal mechanism, and source spectra provide significant constraints on the source models and the state of stress within active tectonic/geologic features.

Records from the recent (1982) New Brunswick, New Hampshire, and Arkansas earthquakes appear to have a strong high-frequency component. This could have significant impact on the type of plant components that would be susceptible to damage from a small nearby earthquake and could change the importance of documenting the "Tau" effect* and its possible frequency dependence.

1.1.2.2 Propagation/Attenuation Characteristics

There are several aspects of the propagation of seismic energy that are problematic. They are the variation of the attenuation function with distance (lateral heterogeneity) and the dependence of "Q,"** the attenuation factor, on seismic wave frequency and direction of motion.

Some very promising work has been done on attenuation by St. Louis University and MIT with partial NRC support, but this must be broadened to more fully address the problems mentioned above, particularly the frequency dependence of "Q". Dr. Singh's work at St. Louis University has provided some rudimentary information on the regional variation of "Q" between 0.5 and 3.5 Hz. Information about the high-frequency component of motion is important for the NRC.

1.1.2.3 Site Response Characteristics

Under this issue there are two basic problems, calculation of site-specific response spectra and estimation of the site soil response. There are currently no widely accepted techniques available to calculate site-specific response

*The "Tau" effect is an observed phenomenon related to the wavelength filtering capacity of large structures such as a power plant foundation. It is postulated that a large structure could filter strong ground motion.

**"Q" is the attenuation factor and is inversely proportional to the decrease in amplitude of a seismic wave as it passes through a medium, i.e., the higher the "Q", the smaller the change in amplitude.

spectra. Site-specific spectra may be used as substitutes for Reg. Guide 1.60. There is virtually no guidance available on calculating them, and considerable applicant and NRC staff effort is spent in development and evaluation.

Also included in site-specific response is the issue of the partition of seismic energy between the horizontal and vertical components. The work of Dr. Gupta of Teledyne Geotech indicates that the ratio of the "average" horizontal to vertical acceleration may vary by as much as 200-300%.

1.1.2.4 Soil Failure

Many nuclear power plants in the East are sited on soil. Soil settlement and liquefaction can become a significant issue when ground shaking greater than the SSE is considered. There are numerous predictive models for soil settlement and liquefaction, but there has been little work to validate them.

1.2 Handling Uncertainties

A fundamental issue that needs to be addressed concurrently with attempts to quantify and reduce the uncertainty in seismic hazard assessment is how to handle the uncertainty in a regulatory environment. Some of the techniques used to handle the seismic hazard uncertainty require further analysis and development.

Two significant factors affect the implementation of STPP research results into regulatory decisions: (1) how the results will be used in regulatory decisions and (2) the nature of the results to be used. Probabilistic risk assessment (PRA) is one technique that takes the results from STPP and builds a tool that can be used in the regulatory process. Thus, part of the responsibility of ESB under STPP would be to make certain that the STPP results and their associated uncertainties were in a form compatible with PRA techniques. A number of PRAs that have included external events have identified seismic hazard as one of the dominant contributors to overall risk.

Historically, seismic design parameters are presented in terms of anchorpoint acceleration values and then Reg. Guide spectra. These are not the input specifications that PRA practitioners can most accurately and easily handle. They would prefer input in the form of probability density distributions of ground motion incorporating estimates of sensitivity to spectral distribution, duration, mode, and the like. Development of that type of information requires improvement of existing methods and development of new ones to handle the individual uncertainties and their interrelated sensitivities. This is an important step in the development of techniques to compare the seismic risk at two different sites or to compare the relative significance of internal and external contributors to the overall risk. However, within the time frame of a normal life cycle of a nuclear power plant, there will always be some uncertainty in the assessment of seismic hazard in the eastern seaboard. This uncertainty needs to be factored into the decisionmaking process.

2 PROGRAM PLAN

The program plan to resolve the technical issues described in the previous section is presented here in a parallel format. There are two parts: programs related to quantification and reduction of uncertainty in seismic hazard assessment and programs related to dealing with the uncertainty. The programs described in the first part generally involve basic data collection and interpretation. The programs described in the second part generally involve probabilistic analysis of existing data sets.

2.1 Estimation and Reduction of Uncertainty

The programs concerning the estimation and reduction of uncertainty are grouped into regional programs and topical programs. The regional programs consist of operation of seismic networks and geophysical/geologic investigations of key regions. The topical programs consist of studies related to generic issues rather than source zone problems. There is some overlap, the seismic networks also contribute to the topical program.

2.1.1 Regional Programs

The uncertainty in the characterization of seismic source zones is the fundamental issue addressed by the regional programs. This uncertainty arises from several aspects of the issue: delineation of the seismic source zone, estimation of the maximum credible earthquake, characterization of source parameters, occurrence relationships, and the like.

The programs are subdivided into the previously described four regions. This subdivision is partially because the nature of the problems or issues vary with the regions and the tectonic processes may differ in the different areas.

The role of the seismic networks as the mainstay or backbone of the regional part of the STPP will be described in a separate section. This deviation

from the regional presentation of the program plan is being made so that the common element for the networks will not have to be repeated for each region.

Regional Seismographic Networks

The four regional networks and one independent local network are the mainstay of the regional STPP (Table 1). Operation of these networks provides data of primary importance in identifying seismic source zones, depth, recurrence statistics, attenuation information, earthquake source parameters, and other basic seismological data.

Table 1

1. The Northeastern United States Seismographic Network (composed of six local networks, about 130 stations)
2. The Southeastern United States Seismographic Network (four local networks, about 65 stations)
3. The New Madrid/Anna Ohio Seismographic Network (three local networks, about 65 stations)
4. The Nemaha Ridge Seismographic Network (two local networks, about 25 stations)
5. The Northern Oregon Seismographic Network (a single local network, about 10 stations)

As part of the previous STPP, a program was initiated to promote the upgrading of seismographic network instrumentation. The first phase of the transition from analog recording to full digital recording of digital signals, i.e., conversion to digital recording of analog signals, is nearly complete. The second phase, development of a number of high-quality digital test stations to provide digital signals for several networks, is progressing.

The issues that this upgrading and testing address are twofold. The first is mainly economic, and the second is the number of significant seismological problems that are critical to siting nuclear facilities and do not appear to be readily solvable with the current narrow-band limited-dynamic-range seismographs. One of these significant problems is hypocentral depth determinations.

Significant progress has been made in specifying the epicentral location of recent seismicity in the East. However, the depth is still difficult to obtain. It is becoming apparent that, without either more seismographic stations or new analytical techniques, the depth is going to remain elusive. The proposed solution of increasing the information content of the current recording capability at a number of test stations is more economical and scientifically productive than adding more stations. By increasing the information content, it is possible to reduce the uncertainty in the depth term by making greater use of the earthquake time series. Accurate knowledge of the depth of epicenters is required for correlation of seismicity with "suspect" geologic structures. There is apparently little correlation between seismicity and surface-mapped geologic features. Uncertainty about the depth of seismicity and the sub-surface trend of the feature contributes significantly to this lack of correlation. Accurate depth information is also required as input to fault plane solutions earthquake modeling codes used to generate synthetic seismograms, spectra, and attenuation information.

Relationship Between Seismographic Networks and Geological/Geophysical Investigations

However different the regional issues are, the relationship between the seismographic networks and the geological/geophysical studies remains the same. The networks provide the basic seismicity data, location, depth and magnitude, which are the fundamental data for establishing the seismic source zones and the recurrence relations in them. This information is used to select the areas that are currently seismically active and thus most likely to be productive for geological and geophysical investigations. One of the primary objectives of the STPP is to establish, if possible, the relationship between seismicity and tectonic features.

One of the important contributions of the geological and geophysical investigations is their ability to augment a short seismic history. Geological and geophysical investigations such as stratigraphic studies and geodetic studies can confirm delineation of seismic source zones by "lengthening" the seismic record, in situ stress measurements can confirm focal mechanism-derived stress directions, and seismic profiling can confirm crustal structure models. With

the added dimension of geological and geophysical investigations the characteristics of seismic source zones can be established with more confidence.

2.1.1.1 Southeastern United States

A primary issue in the Southeast is determination of a causative mechanism or structure of the 1886 Charleston earthquake. A number of hypotheses have been proposed and the major effort of the STPP in the Southeast is testing these hypotheses for their relevance to eastern seismicity both in the immediate Charleston area and in other areas in the Southeast. The USGS is the prime contractor to the NRC in the immediate Charleston area; its program there is partially funded by the NRC and the USGS.

The program in the Southeast has 6 geological/geophysical projects.

1. Seismic Reflection Profiling in Giles County, Virginia

The purpose of this project is to investigate a postulated structure that is suggested to be the source structure of the Giles County seismic zone. A deeply buried planar structure, interpreted as an Iapetan normal fault re-activated by modern stresses, has been proposed as the source structure based on the alignment of seismicity. This project will make use of some state-of-the-art Vibroseis techniques being developed by a Virginia Polytechnic Institute (VPI) consortium to penetrate the shallow karst structures in Giles County. This is a cooperative cost-sharing project coordinated by VPI with State, Federal, and oil industry support. The NRC support will be about 10% of the total cost.

2. Seismic Reflection Profiling and Supportive Geology in Central Virginia

The primary purpose of the project is to determine the structure of the earth at hypocentral depths in the Central Virginia seismic zone. Preliminary studies show a promising correlation of earthquake hypocenters with structure

defined by multichannel seismic studies. The structures are visible at the surface as lithologic boundaries that are fault controlled. The supportive geology in FY 84 will include neotectonic studies of young deposits to determine if there is recent movement.

3. Neotectonics of Southeast

The purpose of the investigation is to gain neotectonic information along several proposed seismogenic structures in the Southeast to see if there is evidence that they have been reactivated. Three structures will be investigated: a Triassic Basin, a structure related to the decollement, and one other. The locations of these structures will be determined during the investigation.

4. In Situ Stress Measurement

The direction of in situ stress defines what faults can be active in a region and how they can move. Several measurements will be conducted at critical locations. The first will be conducted in the Central Virginia seismic zone, where the structure and the distribution of earthquakes are known. The stress information will give critical information on the type of motion occurring on the fault. The next site chosen will probably be at or near a Triassic Basin.

5. Charleston Clarification Project

A project will be initiated in FY 84 to solicit information critical for testing hypotheses on the cause of the Charleston event. The project will build on results of the USGS program, the neotectonics, and the in situ stress projects.

6. U.S. Geological Survey Charleston Projects

The USGS has been the major investigator in the Charleston region. This work was cooperatively funded by NRC and USGS. The work includes operation of a seismographic network that is being upgraded to include some three-axis

instruments. Considerable seismic reflection profiling has been conducted both on shore and off shore. This led to the discovery of the Helena Banks and Cooke faults. Several deep boreholes and many shallow boreholes were drilled to define the stratigraphy of the region.

Future work in the region may continue similar types of projects. The impact of the USGS clarification of its position on Charleston is being fully factored into the annual formulation of the USGS-NRC program.

2.1.1.2 Northeastern United States

In the Northeast there are some suspicious structures, e.g., the Ramapo fault system, and some activities that may be related to seismogenic mechanisms, e.g., the rapid crustal subsidence along the coast of Maine. However, the level of understanding is not as well developed as in the Southeast where several models have been proposed and can be tested. In the Northeast the models are being developed.

The Ramapo fault is a critical structure that has been targeted for detailed studies. There is an apparent correlation of earthquake epicenters with the strike of the feature. The geology of the zone is well known, a Triassic basin parallels older features. In situ stress measurements and multichannel seismic reflection surveys will be conducted under this seismotectonic plan. With these results, the level of knowledge about the Ramapo seismic zone will be very high, and the relationship between the structure and seismicity will be made clearer.

The program in the Northeast has 4 geologic/geophysical projects.

1. State of Maine Cooperative Study

There is a cooperative agreement with the State of Maine to investigate rapid subsidence along parts of the coast. The rates are up to 9 mm per year, and seismicity is spatially associated with the subsidence. This is important

because the subsidence is occurring along the Bay of Fundy rift. The re-activation of rifts has been proposed as the cause of the Charleston event and other events in the Eastern United States. The State of Maine also assists in earthquake investigations in the region, such as the 1982 New Brunswick events.

2. Neotectonics of Northeast/New England

Critical structures will be investigated for evidence of recent movements or reactivation. These will include at least one Triassic basin. The area of the Gaza, New Hampshire, earthquake and areas near the Long Island epicenters will also be investigated. Verification of the Adirondack uplift is also a possible target. Given the success of paleoliquefaction studies in New Madrid, these are also likely studies.

3. In Situ Stress Measurements

In situ stress measurements will be conducted in the Ramapo seismic zone and the Moodus, Connecticut seismic zone. This is to gain information concerning which faults may be active and what type of motion is likely on them. This information should help clarify the type of fault motion that is occurring on the Ramapo. Previously, reverse faulting was suspected; however, recent seismic results suggest strike slip faulting. The measurements will be conducted in FY 84. Other areas will be targeted for measurements, including, perhaps, the site of the Gaza, New Hampshire earthquake.

4. Seismic Profiling of the Ramapo Fault Zone

Three cross sections are planned across the Ramapo fault zone to define the structure at hypocentral depths. The cross sections have been chosen on the basis of the well-mapped surface geology and the distribution of earthquakes. The USGS is supervising the study.

2.1.1.3 New Madrid/Anna, Ohio

The source of seismicity in the New Madrid region is reasonably well established. The seismicity is probably occurring along a continental rift

zone. The rift is too deeply buried to be detected geologically; however, evidence of recent movement is observable at the surface. The regulatory issue is what is the extension of the rift to the south and north. Geophysical data indicate that the rift spreads out to the north into several different branches. Reflection seismic studies suggest that one of the branches continues to the northeast toward the Anna, Ohio, seismic zone; however, the strong magnetic signal that defines the Maine part of the rift is weaker there.

The relationship of the Arkansas 1982-83 swarm to the New Madrid activity is not yet known. The issue is whether the swarm occurred south of the New Madrid zone or not. This suggests the possibility of even further southern extensions.

NRC work is directed primarily at determining the extent of the seismic zone. This work is proceeding by three processes: seismic monitoring, geologic investigations, and geophysical investigations.

The program in New Madrid has 2 geologic/geophysical projects.

1. Geologic Investigations for Evidence of Seismicity

There is geologic evidence of the seismic activities within the documented New Madrid seismic zone. The most striking evidence is the Lake County uplift. There are also numerous sand blows in the area. Geological investigations outside of the documented seismic zone are directed at determining if such evidence is present along the proposed extension of the Reelfoot Rift. At present, they have not been found. The funding level for this work is being reduced after FY84.

2. Extension

The definitive evidence for the Reelfoot Rift has been geophysical, both by seismic reflection and refraction and potential field studies. Geophysical studies are proposed through FY85 to examine the proposed extension of the Reelfoot Rift to determine if seismogenic structures are present. Preliminary studies show the presence of faulting along some of the extension, but the age is old.

2.1.1.4 Nemaha Region

The research activity in the Nemaha Region consists of the operation of a seismic network. Because of the recent discovery of a possibly active fault in Oklahoma, the Meers fault, a limited trenching program may be initiated there.

2.1.1.5 Pacific Northwest Region

The research activity in the Pacific Northwest consists of the operation of a seismic network. Presently there is no geophysical/geological work planned.

2.1.2 Topical Program

The Topical Program is designed to address the topical issues raised in the previous section.

2.1.2.1 Source Parameters

A number of projects have been initiated under this topical element. The most important of these currently is the acquisition of a "viable" data base of strong-ground-motion accelerograms of Eastern U.S. earthquakes. This is being accomplished by a continuing project to acquire and install an array of accelerographs in the Eastern U.S. to augment the instrumentation programs of the U.S. Army Corps of Engineers and the Veterans Administration. (The instrumentation for these two agencies is usually at dam sites or Veterans hospitals.) This project will support the acquisition and installation of about 50 strong-motion accelerographs. A number of these instruments will be deployed close to a "host" institution so that they may be quickly redeployed in the event of a moderate to large eastern earthquake.

The NRC is also supporting several projects for the analysis and dissemination of some of the existing eastern strong motion accelerograms in particular those from the 1982 earthquakes in New Brunswick, New Hampshire, and Arkansas. Currently as part of the NRC-USGS Interagency Agreement, the NRC is funding detailed analysis of the New Brunswick and Arkansas data set and some field work in New Brunswick (NB) with the Canadians. This work is intended to develop more precise data on the crustal structure at the NB site to more

fully explain the NB accelerograms. The reason for the high accelerations for small earthquakes remains a puzzle. The U.S. Army Corps of Engineer records from the New Hampshire earthquakes are available as NUREG/CR-3327 with magnetic computer tapes from the NOAA data center in Boulder, Colorado.

An explicit program for work under this subelement has not been developed but work of the above type will continue to be supported.

2.1.2.2 Propagation/Attenuation Characteristics

Much of this work is being carried out as part of the seismic data analysis conducted by the regional networks. It is being highlighted as part of the Topical Program because of its importance. It is also included here because the data base that is currently available is too sparse to provide propagation information on a regional scale and thus should be handled on a broader scale. (This problem of paucity of data is further addressed elsewhere in this program plan by improvements in network instrumentation.)

The limited amount of available data is being used to the fullest extent possible. Projects being planned will use data from special systems that are currently being operated or were operated in the past by DOE, DOD, and others for specific limited projects. The data from these sources may significantly augment the network data.

2.1.2.3 Site Response Characteristics

A major effort is planned in the area of site-specific response development. It is anticipated that the exact focus of this effort will be developed following the result of a major workshop on the subject that was held in July 1983. This workshop was jointly supported by the NRC, USGS and other sponsors and is designed to establish the state of the art on site-specific response problems. We plan that this new work will explicitly address the problem and the representation of ground response in excess of the SSE.

A current project in this area that overlaps with the two previous elements is a project with Structural and Earthquake Engineering Consultants entitled

"Selection of Earthquake-Resistant Design Criteria for Nuclear Power Plants; Methodology and Technical Basis." This project is to examine the use of geologic data in the characterization of seismicity, the scaling of strong ground motion, and the scaling of response characteristics for various site and earthquake parameters.

2.1.2.4 Soil Failure

Development of a validated model for soil failure is the goal of the soil failure project. A large number of nuclear power plants are on soil foundations; because PRAs are examining the risk of nuclear failure due to ground shaking at 2 to 3 times the SSE, the potential for soil failure becomes a contributor to the overall risk. There is presently no validated code for soil failure/settlement.

In addressing this issue, we have taken advantage of the experience of the Corps of Engineers who have long been concerned with the effects of soil failure on their structures. They have considerable experience in both laboratory and field studies. They conducted for the NRC a detailed study of available soil failure codes and concluded that DESRA, a code developed by Prof. Liam Finn of the University of British Columbia, was the best candidate code for validation. There were three reasons: the physical basis of the code was the best, the code utilized standard engineering data, and it had been partially validated by data taken at an artificial island in Japan during an earthquake.

The validation experiments will be conducted at Cambridge University under a subcontract using soil samples tested in a centrifuge. A sand saturated with glycerine will be loaded with model structures and subjected to model seismic loads. Pore pressure and displacements will be monitored during the loading.

As an independent effort, the possibility of a full-scale validation of DESRA using data from the Nevada Test Site will be investigated.

In FY 1984, the NRC will participate in a soil settlement workshop sponsored through The National Academy of Science, the National Science Foundation, and the U.S. Geological Survey.

2.2 Program to Address Uncertainties

The objective of this portion of the STPP II is to develop techniques for the analysis or evaluation of existing data sets. Currently these projects all have some probabilistic aspect. There are two projects under this program already in place, one more in the procurement process, and one still being formulated.

2.2.1 Seismic Hazard Characterization of the Eastern United States (SHC)

This is a joint project between the Offices of Nuclear Reactor Regulation (NRR) and Nuclear Regulatory Research (RES) that is being conducted at LLNL. It is an outgrowth of the probabilistic seismic input for the Systematic Evaluation Project (SEP) and the Site Specific Spectra Project. It is designed to provide a simplified seismic input for PRA and to be used by NRR for resolution of the issues raised by the USGS clarified position on the Charleston Earthquake.

A principal objective of the SHC project is to improve the basic project computer code developed for SEP and to produce seismic hazard curves with appropriate sensitivity studies for ten test sites. The project uses a solicitation of expert opinion as the source of basic seismological data. The seismicity panel provides seismic source zone maps, estimates of maximum magnitude earthquakes for each source zone, and estimates of earthquake recurrence parameters. The attenuation panel provides input on the attenuation and source parameters to be used to propagate the earthquake ground motion from the source to the site.

Results for the ten test sites are scheduled to be ready by mid-February 1984 at which time the codes will be turned over to NRR as a licensing tool. It is anticipated that preliminary hazard curves will be available for all eastern U.S. nuclear power plant sites by about mid-1984.

2.2.2 Earthquake Recurrence Intervals for Nuclear Power Plants

This project is being carried out by ERTEC to provide advice to RES concerning the quality of available techniques for calculating earthquake recurrence parameters. The project consists of five tasks: (1) identify the classes of available techniques for estimating recurrence intervals and recommend some for evaluation, (2) develop an evaluation scheme, (3) evaluate the techniques, (4) make recommendations to RES based on the evaluation of the techniques, and (5) develop a new technique at the option of RES. One of the important aspects of this project is that the contractor is to explicitly address the problems and uncertainties associated with recurrence interval estimates out to very long times, as great as 100,000 and 1,000,000 years.

2.2.3 Selection of Earthquake-Resistant Design Criteria for Nuclear Power Plants; Methodology and Technical Bases

The proposed topics are grouped into five separate tasks. The first two, to be carried out during the first year of effort, will provide for formulation and selection of models to describe slip rates at known active faults and to scale strong motion close to these faults. The third and fourth tasks, planned for the second year of the effort, will update the direct-scaling relationships of spectral amplitudes of strong ground motion and will update and further generalize the Uniform Risk Spectrum method we developed some five years ago (NUREG-0406 Vol. 2). The fifth and final task, planned for the third year of the effort at the option of NRC, will produce the recommendation on standard (typical) and special case methods and procedures for use in licensing and will combine deterministic with probabilistic methods of analysis for selecting a balanced seismic design basis.

2.2.4 Site-Specific Response Program

This project is in the preliminary planning stage. It will develop techniques for calculating site-specific response spectra and will specifically address the problem and the representation of ground response in excess of the SSE. It was also briefly mentioned under Topical Programs.

3 RELATION OF STPP TO OTHER PROGRAMS

In this section, the STPP II addresses its relationships with the three groups with which it is associated. The first group is composed of users of STPP products within the NRC. This group includes NRR, NMSS, DRA/RES, and DET/RES. The second group is composed of supporters of earthquake hazard research with whom the ESB has informal or formal cooperative agreements. This group includes Federal organizations such as the USGS and FEMA and State agencies such as geological surveys. The third group is composed of private sector organizations.

3.1 NRC Seismic Research

3.1.1 RES

Research related to the uncertainties in seismic risk is contracted for by three divisions within the Office of Nuclear Regulatory Research: Division of Health, Siting and Waste Management (DHSWM); Division of Engineering Technology (DET); and Division of Risk Analysis (DRA). The interface between DHSWM and the other two RES divisions is briefly described below.

DET is concerned primarily with the mechanical response of nuclear power facilities to earthquakes. They need seismic hazard input to conduct their work. They supported some research on hazard estimation as part of SSMRP. The Seismic Hazard Characterization for the Eastern U.S. (described in 2.2.1) is a spinoff from the hazards part of SSMRP. That project, which is being monitored by DHSWM, is intended to provide a simplified seismic input for SSMRP use. There is a DET and DHSWM interface in soil mechanics also. DHSWM sponsors research concerned with soil settlement, soil failure, and liquefaction, and DET sponsors research concerned with soil-structure interaction.

DRA is concerned with seismic hazard as a element in the assessment of seismic risk at nuclear power plants. The Full Scope Risk Assessment Program is a major program in DRA that includes external input such as seismic information.

This is the principal interaction point between DRA and DHSWM. DHSWM provides information to DRA for development of seismic input.

3.1.2 NRR

RES coordinates its research activities on seismic hazards very closely with its counterparts in NRR. As described in 2.2.1 of the Program Plan, NRR and RES are jointly supporting the development of the Seismic Hazard Characterization protect. RES, in effect, is sponsoring the development or improvement of a computer code for hazard curve calculations, and NRR is supporting its use at specific sites.

3.1.3 NMSS

NMSS, under the high-level waste program, conducts considerable technical assistance in the geologic and geotechnical areas and is concerned with seismic siting and seismic design.

3.2 Other Government Agencies

A number of other Federal agencies have research programs associated with seismic hazard evaluation and reduction. A large portion of this other research effort is associated with the National Earthquake Hazards Reduction Program (NEHRP) with FEMA serving as the "Lead Agency." The four major participants in the NEHRP are FEMA, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards. The USGS is the principal agency in this group supporting research related to earthquake hazards in the U.S. The NSF is responsible for fundamental geological and seismological research and for most earthquake engineering research.

In addition to the NEHRP, other agencies such as the Departments of Energy and Defense have programs that provide basic geological, seismological, and engineering data and analysis techniques that are useful to the NEHRP.

3.2.1 FEMA and the NEHRP

FEMA as the "Lead Agency" for NEHRP is charged to coordinate a national effort to counter the serious earthquake threat in the United States. As stated in the law, its objectives are:

- o The development of technologically and economically feasible design and construction methods and procedures to make new and existing structures, in the areas of seismic risk, earthquake resistant, giving priority to the development of such methods and procedures for nuclear power generating plants, dams, hospitals, schools, public utilities, public safety structures, high occupancy buildings, and other structures which are especially needed in time of disaster;
- o The implementation in all areas of high or moderate seismic risk, of a system (including personnel, technology, and procedures) for predicting damaging earthquakes and for identifying, evaluating, and accurately characterizing seismic hazards;
- o The development, publication; and promotion, in conjunction with state and local officials and professional organizations, of model codes and other means to coordinate information about seismic risk with land-use policy decisions and building activity;
- o The development, in areas of seismic risk, of improved understanding of, and capability with respect to, earthquake-related issues, including methods of controlling the risks from earthquakes, planning to prevent such risks, disseminating warnings of earthquakes, organizing emergency services, and planning for reconstruction and redevelopment after an earthquake;
- o The education of the public, including State and local officials, as to earthquake phenomena, the identification of locations and structures which are especially susceptible to earthquake damage, ways to reduce the adverse consequences of an earthquake, and related matters;

- o The development of research on
 - a. ways to increase the use of existing scientific and engineering knowledge to mitigate earthquake hazards;
 - b. the social, economic, legal, and political consequences of earthquake prediction;
 - c. ways to assure the availability of earthquake insurance or some functional substitute; and
 - d. the development of basic and applied research leading to a better understanding of the control or alteration of seismic phenomena.

In addition to coordinating the NEHRP activities, FEMA leads the effort to improve the seismic safety of Federal buildings and conducts a program of earthquake preparedness planning for areas of high and moderate seismic risk. FEMA was one of the cosponsors of the May 1983 Charleston Earthquake Workshop.

3.2.2 USGS

The U.S. Geological Survey is the principal Federal agency charged with carrying out the geological and seismological aspects of NEHRP. The second objective of the Earthquake Hazard Reduction Act of 1977 (P.L. 95-124 [S.1267]) specifies "the implementation (of NEHRP) in all areas of high or moderate seismic risk."

Without providing an exact definition of the term "high or moderate seismic risk," the USGS is currently carrying out an earthquake hazards and prediction program under the auspices of NEHRP which places an overwhelming majority of its NEHRP funds in California.

For FY 1984 the USGS is reported to be developing a program plan to address seismicity problems in the Eastern U.S. The thrust and content of this plan is being developed.

In addition to the relation between the USGS and the NRC implied by the above, the USGS is the NRC's prime contractor for seismic hazard research in the Charleston, S.C., area. The USGS also does work for the NRC on the topics of strong ground motion and probabilistic sensitivity. Table 1 lists current USGS protects.

3.2.3 NSF

The Geophysics Program of NSF sponsors research on earthquake processes and phenomena. The Civil and Environmental Engineering Program sponsors work on earthquake engineering and socioeconomic implications of earthquakes. The research supported by DHSWM under STPP more closely interfaces with the Geophysics Program at NSF while the DET program interfaces more closely with the Engineering Program.

A principal difference between the DHSWM program and the NSF Geophysics Program is that the former is structured to produce a specific product, i.e., earthquake hazard information, and the latter is structured to produce basic scientific advancements.

Coordination between the two programs, NRC and NSF, is very good, as evidenced by the numerous jointly funded projects such as the recent Charleston Earthquake Workshop and the Soil Settlement/Liquefaction Workshop being planned. This close coordination and cooperation is fostered by the National Academy of Sciences' Interagency Geophysics Discussion Group.

3.2.4 Corps of Engineers

The Corps of Engineers (COE) is concerned with seismic hazard primarily as it affects their structures. They have produced a seismic hazard map of the Central U.S. and are working on one for the eastern seaboard. They are actively concerned with the problems of soil settlement and liquefaction.

The Corps maintains an array of strong-motion accelerographs at many of their dams. This is particularly important in the Eastern U.S. where not many such instruments are deployed. These instruments are deployed to provide COE with data specifically applicable to dam safety so some of the data is not

directly applicable to more generic safety problems. In spite of this limitation DHSWM and COE have been able to successfully cooperate on a strong motion data analysis project. DHSWM and COE are also cooperating on a joint project to validate theoretical models for soil settlement or liquefaction induced by earthquake ground motion.

3.2.5 Veterans Administration

The Veterans Administration maintains strong motion seismographs in some of its facilities. Although this is a minor effort, the data from them is potentially very significant.

3.2.6 State Agencies

A number of States conduct research in geology and seismology, primarily through the various State geologic surveys. Generally, their work is more related to economic aspects of geology such as mineral deposits or water resources. Some States do have hazard-related research or research directly related to NRC information needs. The DHSWM presently has cooperative programs with several States to share costs on projects of interest to both.

3.3 Private Sector Research

3.3.1 Electric Power Research Institute (EPRI)/NRC Interactions

EPRI has developed a draft plan to assess probabilistic seismic hazard in the Eastern United States in response to the USGS clarification of position on the Charleston earthquake and to the NRR plan to address that clarification. The EPRI plan is a parallel but independent effort to the hazard assessment being conducted by NRR. NRR is using the methodology developed by the joint RES/NRR Seismic Hazard Characterization project mentioned earlier in the STPP. The current EPRI plan is primarily a response to licensing initiative; however the EPRI plan leaves open the possibility for a research effort to clarify some technical issues. If EPRI begins such work, it will be necessary to coordinate efforts. They are kept informed of our activities, and they received a copy of the previous seismotectonic program plan.

APPENDIX A

BUDGET

FOR THE

SEISMOTECTONIC PROGRAM PLAN

Table 1 is the proposed budget required to carry out the STPP. The total cost represents the level of funding necessary to carry out the essential elements of the STPP. (These costs are shown in the columns without asterisks.) The total funds available represents the level of funding currently available to NRC from Congress. (These funds are shown in the columns with asterisks.) The difference between these two figures beginning in FY 1985 is \$1.2 million. This money is to be raised by ESB in the form of cost-sharing and cooperative agreements with other government agencies, universities, and private organizations.

TABLE I

BUDGET

	FY84	FY85	FY85*	FY86	FY86*
NE					
Seismographic Networks	870	910	900	900	900
Geology/Geophysics	475	650	500	600	500
Regional Total	1345	1560	1400	1500	1400
SE					
Seismographic Networks	600	625	600	650	600
Geology/Geophysics	810	1360	1000	1235	1000
Regional Total	1410	1985	1600	1885	1600
NM/AO					
Seismographic Networks	355	375	350	380	350
Geology/Geophysics	300	130	100	120	100
Regional Total	555	505	450	500	450
Nemaha Ridge					
Seismographic Networks	130	135	100	140	100
Pacific Northwest					
Seismographic Networks	160	105	-	100	-
Totals					
Regional Programs Total	3600	4290	3550	4125	3550
Topical Program Total	865	560	400	700	400
Probabilistic Program	735	850	550	875	550
TOTAL	<u>\$5200</u>	<u>\$5700</u>	<u>\$4500</u>	<u>\$5700</u>	<u>\$4500</u>

APPENDIX B

NATIONAL CENTER FOR SEISMOLOGICAL STUDIES

One of the truly significant problems that is facing the entire seismological community is the efficient management, both in time and cost, of the data that is currently being collected. A report entitled "Effective Use of Earthquake Data" written by the Panel on Data Problems in Seismology of the Committee on Seismology of the National Academy of Sciences/National Research Council was published in August 1983. To quote that report, "the most important recommendation of this panel is that a National Center for Seismological Studies be established that will overcome the key data management problems that we have identified and enhance the availability and effective use of high-quality data sets by the entire seismological community."

An unofficial working group including several members, past and present, of the Committee on Seismology is attempting to develop a program plan for the implementation of this recommendation. One of the solutions involves the use of the Center for Seismic Studies operated by the Defense Advanced Research Project Agency of DOD in Rosslyn, Va. Discussions involved use of the center itself or as a prototype depending on DARPA's commitments and the availability of support. The establishment of a national nonprofit corporation was one of the vehicles suggested for supporting the center with contributions from all the organizations making use of the data. The contributions would be expected to reflect in some sense the contributor's need for the information. Thus the USGS, FEMA, and NSF, who have major responsibilities under the Earthquake Hazards Reduction Act of 1977, might be expected to be major contributors to the corporation. The NRC, because of its continuing concern for the safety of nuclear power plants, might be expected to be a contributor. The same very clearly applies to the nuclear utility owners as well. There will be further comment on this issue later in this section.

As currently being discussed, the principal function of the National Center for Seismological Studies would be to serve as a data facility. This function requires some explanation. One of the truly onerous and time-consuming tasks

of seismological research is collection and preparation of a suitable data base for analysis. The computer systems distributed by the USGS in about 1978-79 were intended to help reduce this burden to allow the seismologist more time for productive research. The Defense Advanced Research Projects Agency (DARPA) center is designed to collect, collate, and disseminate its data base in an extremely efficient manner and to provide a master file of data analysis and display codes for research problems. The data management problem is handled once and as close to the data source as practical. This would provide more efficient use of manpower and financial resources.

When such a National Center comes into being it can serve as the appropriate nucleus for a National Digital Seismographic (NDS) Network. In the most general terms, the NDS network would be composed of three-component broad-band seismographs with high dynamic-range digitization of the signals at the seismometer site with final permanent recording at some central site. This equipment is in sharp contrast to the low-dynamic-range narrow-bandwidth seismographs with analog recording that are currently in use. Very simply put, the principal advantage to such a new system would be the significant increase in the information content of the recorded signal.

This may be well illustrated by the preliminary results of an NRC supported experiment in New Brunswick. A number of portable high-dynamic-range seismographs were temporarily deployed in the vicinity of the 1982 New Brunswick earthquakes. Preliminary results indicate that seismic signals above 100 Hz were recorded. These are well above the $f_{\max}$ predicted for this case by current theory. Thus, these new recordings may have a fundamental impact on theories about earthquake source mechanisms.

The Earth Sciences Branch (ESB) is supporting some experimentation with these broad-band seismographs and the development of some of the necessary analysis codes. (Some of this effort is being conducted in cooperation with the Air Force Office of Scientific Research.) This work is being carried out to explore the advantages and limitations of such a system technically and to provide the NRC with some experience using this type of data to resolve regional seismic issues.

One of the recurrent problems concerning RES management is the cost of operating the regional seismic networks in the Eastern U.S. This is particularly worrisome when it is recognized that there is no point in the foreseeable future beyond which the NRC will not need seismic information to carry out its mission. A National Center for Seismological Studies and a National Digital Seismographic Network operated by a nonprofit corporation that is capable of accepting funding from private as well as governmental organizations may be the mechanism that would resolve this problem.

A vigorous campaign is being carried out to increase the level of outside financial support for the STPP. As stated in Appendix A of the STPP Budget, ESB is committed to developing \$1.2 million from external sources to support the STPP in FY 1985 and beyond. The National Center and Network represent two excellent vehicles to carry out this campaign, i.e., some of the financial burden for the eastern seismographic networks could be more evenly divided among the users of the data.

APPENDIX C

PROGRAM ELEMENTS REQUIRED TO MORE EXPEDITIOUSLY
RESOLVE SEISMIC ISSUES

The availability of financial resources is always one of the important controlling factors on how expeditiously a research issue can be addressed. In this appendix we present a series of program elements that, if they are funded now rather than at some time in the future, may lead to a more rapid resolution of the seismic issues. All of these elements are important to resolution of the issues and very probably will have to be conducted in the future. They were not selected for inclusion in the STPP because of resource constraints. The projects established in the STPP are those, based primarily on the informed judgment of the ESB staff, that are most needed to resolve the seismic issues in a timely fashion.

In this appendix, other key problems in the seismotectonics of the East are defined along with the expected impact of the results. The projects are seismological and geologic/geophysical. The seismological investigation involves more accurate location of earthquake hypocenters, and description of source parameters, propagation characteristics, and site-specific response characteristics. The geologic/geophysical investigation involves determination of the structure, strain and stress of the earth's crust at hypocentral depth. Both the seismologic and the geologic/geophysical investigations address the key issue of what is causing the earthquakes.

Seismological Elements

In this appendix, the seismological elements will not be separated into regional, topical or probabilistic categories. The main difference between the program presented here and in the main body of STPP is the compression of the milestone schedule. There are five elements.

1. Acceleration of the upgrading of the regional networks into the National Digital Seismographic Network and the deployment of strong ground motion records in the eastern U.S. are probably the two most important elements for this program. A delicate balance of time must be maintained for the first element because it cannot be allowed to develop into an NRC show. Other participants should be allowed some time to come up to speed. The implementation of the Digital Network will allow work on the three elements 2, 3, 4 which are all important to modeling, and propagating, ground motion to the nuclear power plant site and then estimating the amount of seismic energy that will be important to the plant. It is difficult if not impossible to prioritize these elements. The second element should be advanced as quickly as prudent expenditure of funds will allow.
2. Work on propagation characteristics using both new and existing data sets.
3. Development of better information on site specific response characteristics.
4. Development of better information on source parameter characteristics.
5. Development of techniques to handle uncertainties and estimate the sensitivity of regulatory decisions to the various uncertainties.

Geological/Geophysical Elements

The geological/geophysical elements are not as easily handled by simply compressing the milestone schedule. These elements are beyond the time scale of the STPP.

The three major seismotectonic issues that are addressable by geologic/geophysical means are (1) The structure of the Earth's crust, (2) the stress field active in the East, and (3) the recent strain field in the East. These three factors are important in all theories on the cause of seismicity in the East and are important in differentiating among the theories. The one common aspect to virtually all theories on the cause of Eastern seismicity is the

reactivation of preexisting structures. The crustal structure studies define the types of structures present; the stress field defines the type of motion that can occur (or if motion can occur) on the structures; and strain measurement detect if motion occurred and if it is still active.

The seismotectonic problems and the proposed geologic/geophysical projects in each of the areas is described below.

Crustal Structure of Florida, Georgia, South Carolina, and North Carolina

Magnetic surveys and borehole penetration demonstrate that the structure of the crust under the coastal plain in northern Florida, southern Georgia, South Carolina, and southern North Carolina is distinctly different from the crust exposed in the Piedmont of Georgia and the Carolinas and is also different from the crust beneath the coastal plain north of central North Carolina. Rankin called this the Charleston Terrain. It is interpreted to be an old continental rift terrain such as the East Africa Rift System on the basis of lithology of the boreholes that have penetrated it.

The structure of this basement is important because it could be related to the seismicity. Two types of structural studies could be conducted: (1) magnetic and gravity and (2) deep seismic refraction.

Seismic reflection profiles have been conducted in several areas; however, the technique is not sensitive to strike slip motion along faults and does not penetrate deep enough to define a rift. Also, there is a basalt layer in Charleston that is difficult to penetrate by seismic reflection and this masks structures beneath it.

Crustal Structure Near New Brunswick Earthquake Epicenter

One of the most critical areas for study of crustal structure is the area of the New Brunswick Earthquake. That earthquake and its hypocentral area are well known. The process of earthquake generation in that area may be significantly clarified with seismic profiling. Perhaps related to that is the neotectonically active areas in the Pasamaquada Bay area of Maine. Its relation to the New Brunswick Earthquake and the Bay of Fundy area is not clear.

Seismic reflection is probably the best method for crustal studies in the New Brunswick area, though seismic refraction may be the best method in the Bay of Fundy region.

Stress Measurements in the Eastern United States

The current STPP plans for three stress measurements in FY 83/84. Several more are planned for FY 85/86. However, these measurements are relatively shallow, ~300 m. Regional studies of the stress in the midcontinent defined a regionally consistent stress direction that has helped considerably in interpreting the New Madrid seismicity. However, more measurements are necessary to define the stress condition in the East.

Also, deeper measurements are necessary. The measurements to 300 m are reasonable but 1000 m or 1500 m measurements in earthquake hypocentral areas have been very helpful in defining seismogenic mechanics. Potential sites for measurements are (1) an Triassic Basin site, (2) an eastern overthrust splay site, (3) the New Brunswick epicenter site, (4) the Pasamaquada Bay area, (5) the Giles County site, and (6) the Charleston area.

Strain Measurements

The proposed seismogenic mechanisms should be systematically investigated for evidence of strain, both geodetic and geologic (such as terrace movements and paleoliquefaction features). This would involve examining sites for strike slip faulting and also for vertical motions. The sites should include (1) a Triassic Basin, (2) overthrust zones and splays to them, and (3) Mafic Plutons.

Mr. GORE. Thank you very much. Appreciate it.

Dr. Hamilton, based on the Geological Survey's research, what is your best estimate of the return period for large earthquakes in the Central and Eastern United States?

Mr. HAMILTON. Estimates of the return period have been developed for the New Madrid area based on both seismological and geological data. The seismological data has been largely analyzed by Otto Nuttli of St. Louis University, so I'll speak for him—I hope correctly. And then the geological data has been analyzed by Dr. David Russ of our staff and others.

I think the best estimate now is for about a 600- to 700-year return time for a major New Madrid earthquake. Because of the nature of the data, though, this would have to be an uncertain estimate. In fact, we really don't have enough data to even generate a statistically valid estimate of the uncertainty.

Mr. GORE. Uh-huh.

Dr. HAMILTON. Elsewhere in the United States, estimates are much more poorly known. If I were really pressed for an estimate in the South Carolina area, I would probably estimate around a 1,000-year return time, but that estimate could be challenged on several grounds.

Mr. GORE. All right.

Now, how does our capability to predict earthquakes in New Madrid and South Carolina compare with our prediction capability in California?

Dr. HAMILTON. The capability in the east lags behind that in the west. But I have to make clear that the capability to predict earthquakes has not yet been developed. There are some precursors for some earthquakes that have been identified. However, it's clear that not all earthquakes have precursors. We would have to say that a reliable earthquake prediction capability is many years in the future and, in fact, may never be achieved, although some progress is being made toward that goal.

Mr. GORE. Now, you have a program also to provide evaluations of earthquake hazards and risks in earthquake-prone regions. You heard an estimate earlier of damages in the New Madrid area of up to \$50 billion. Do you agree with that, or would you like to comment on that?

Dr. HAMILTON. A number of studies that were referred to earlier were studies that were actually performed by the USGS under contract with FEMA or its predecessor agencies. And, yes, we do concur with these damage estimates that suggest that there could be several billion dollars of damage in major metropolitan areas, and that casualties could run up to the tens of thousands, again depending on the particular area and the particular situations. But, in general, I do concur with the earlier estimates that were given as to the general magnitude.

Mr. GORE. So, for a quake above 8 on the Richter scale in the New Madrid area, you would predict damages of approximately \$50 billion, and loss of lives in what range?

Dr. HAMILTON. The loss of lives could range up into the thousands.

Perhaps I could ask Dr. John Filson, who is the chief of our Office of Earthquakes, Volcanoes and Engineering, to comment on this—

Mr. GORE. Fine.

Dr. HAMILTON [continuing]. And see how he feels about those numbers.

Dr. FILSON. The loss of lives have been put—and the loss of life due to a great earthquake in the east, as has been pointed out earlier this morning, depends on the time of day. In the early morning hours, late at night, people are at home in wood-frame-constructed houses, they are relatively safe. During the evening rush hour, when people are in elevators, coming and going out of large buildings, exposed in transportation systems, you expect a larger loss of life at that time.

The degree of loss of life in a large metropolitan area, such as St. Louis or Memphis, due to a magnitude 8.5 earthquake would be measured, in my opinion, in the thousands; whether it be 4,000 or 10,000 would depend upon, again, the time of day and the particular location of the earthquake.

Mr. GORE. Four or ten thousand.

Dr. FILSON. Yes.

Mr. GORE. \$50 billion is a lot. That's—what are the biggest components of that, buildings?

Dr. HAMILTON. The \$50 billion would, of course, be property damage, and it would occur in single-family housing, apartments, major facilities such as pipelines, electrical substations.

The experience from recent earthquakes shows that—in terms of residential housing—a lot of the greatest damage occurs in unreinforced masonry buildings. This shows up time and time again.

In the Mississippi Valley area, there is a lot of that type of housing that dates from the early part of this century. I think the greatest loss of life would occur in the collapse of multi-story, unreinforced masonry structures that are used for residents.

Mr. GORE. In spite of these estimates that are so high, would you still agree with my statement at the beginning of the hearing that there's no cause for alarm, rather there is good cause for preparation?

Dr. HAMILTON. I certainly agree with that.

Mr. GORE. Now, the Nuclear Regulatory Commission would like to transfer to the Geological Survey some of its seismic monitoring activities. That's correct, isn't it, Mr. Minogue?

Mr. MINOGUE. Yes, sir, that's the substance of it.

Mr. GORE. Does the USGS welcome this proposed change or not, Dr. Hamilton?

Dr. HAMILTON. Let me give a few comments about the background on this.

When the U.S. Geological Survey established its seismograph networks, we chose the areas of greatest earthquake activity. These areas that we chose were California, Alaska, Nevada, Utah, and the New Madrid area in its most active part. We chose these areas because this was where the threat was the greatest, and also, for earthquake prediction purposes, these were the areas where we could observe earthquakes at the greatest rate.

In contrast, the Nuclear Regulatory Commission installed networks in many parts of the East of somewhat lower seismic activity, primarily because that's where they needed the information for their nuclear reactors.

So that's the rationale as to how we got to the situation we're now in.

As to the future, I think there certainly would be some logic in having a coordinated effort for the management of the various seismograph networks. Now, many of these seismograph networks, under any arrangement, should continue to be operated through the universities that have research programs based on them.

Of course, the catch is to continue to fund the networks, regardless of who operates them. If the networks were simply given to the United States Geological Survey without money to support them, that wouldn't solve anything. So the essential ingredient is the continued funding for these networks, regardless of whether they're in the USGS or the Nuclear Regulatory Commission. I think that has to be a primary consideration.

Mr. GORE. Well, that certainly sounds sensible.

Mr. Minogue, geologists used to believe that earthquakes, like the devastating quake in Charleston, SC, back in 1886, were likely only in an area near Charleston. However, recent geological and seismological research has suggested that it may be possible for

similar large earthquakes to occur over much of the eastern seaboard.

In light of that fact, do you require that nuclear plants all over the east coast be designed to withstand earthquakes as great as 7 or larger than 7 on the Richter scale, like the Charleston quake?

Mr. MINOGUE. Mr. Chairman, first, I'd like to address the premise that you made.

Mr. GORE. Sure.

Mr. MINOGUE. From the beginning of nuclear plant licensing review in the Eastern United States, it was recognized that the evidence that would indicate the localization, the potential localization, of the Charleston earthquake was not overwhelming. There are some indications that there are variations in the level of seismic hazard up and down the eastern seaboard, but the case, as far as the Charleston earthquake is concerned, was more a lack of evidence one way or the other because of the difficulty and the varied structures, and so on.

We received—and it was not a great surprise—several years ago from the Geological Survey a clarification of their position on that earthquake, in which they stated that they had not been able to associate that earthquake with a geologic structure, and there was a probability, albeit very low, that the level of ground motion associated with the Charleston-size earthquake could occur elsewhere on the eastern seaboard.

Now, what that has led us to do—and it is essentially suggested by this GS report in terms of the relative level of seismic hazard—is to develop a methodology which I described in my testimony that is an effort to look at the eastern seaboard and have a technique for determining the relative level of seismic hazard at different parts of the eastern seaboard and use that as a basis for reevaluating the seismic design basis for the plants that are there. This work is well along. The methodology is almost developed. We expect it to be fully validated by the end of this year. And it will then be applied to all these plants.

Pending the result of that, we have not made any changes in the seismic design basis required of these plants which are currently in operation.

Mr. GORE. Are any nuclear power plants located near the major earthquake centers in the East, New Madrid, Charleston, Boston, New York?

Mr. MINOGUE. Near, in the sense of a potential for surface faulting that would disrupt the plant, the answer is emphatically not.

However, as has been pointed out by several previous witnesses, the felt area of eastern earthquakes is very large, so even though a plant may be 200 miles from the New Madrid area, the New Madrid earthquake has to be taken into account in the design.

Mr. GORE. Are they? Is it?

Mr. MINOGUE. Yes, sir, it is. That's right. And that's true of these others, as well. I used New Madrid as an example.

Mr. GORE. Well, isn't it true that some of the older nuclear power plants on the east coast, such as Maine Yankee near Portland, were designed and constructed with relatively little consideration of earthquakes, and that many of these plants are now realized to be in more seismically-active zones than first thought?

Mr. MINOGUE. No plant has been licensed without earthquakes being considered. That has never been ignored. There has been——

Mr. GORE. Is that relatively little consideration?

Mr. MINOGUE. There has been an explosion of information and, as the information base has developed through Geological Survey activities and our own and a lot of other people, it is a fact that the relative level of seismic hazard in the East appears higher than it would have been considered, say, in the midsixties. So, for some of these very older plants—and the one you mentioned, I believe, was Maine Yankee—are being reexamined. They were designed for relatively low G values. That is, in itself, probably not that significant in the sense that we've done a lot of reevaluations of various plant designs, and there's clearly a lot of margin in the plants as constructed, particularly in the range from low to midrange G values, because fundamentally the earthquake design requirements are not what determines the structural design. But there is a reevaluation being made of that plant.

Mr. GORE. Well, it's my information that most nuclear power plants are designed to withstand earthquakes up to 5.5 on the Richter scale. Is that——

Mr. MINOGUE. Mr. Chairman, it's not really done that way. They're designed to a particular G value, which is sort of a zero period acceleration that's amplified over a range of frequency response. But it's not quite that straightforward. They're actually designed to a design response spectrum or a set of synthetic time motion records. It's not in terms of magnitude.

Mr. GORE. Can you translate it for me, what magnitude earthquake are they designed to——

Mr. MINOGUE. Not really, because we're not really talking about the same thing.

The magnitude of the earthquake is a measure of the energy release. And the design basis takes a vibratory input and assigns a value to that and assigns a frequency distribution. It really——

Mr. GORE. What about the Mercalli scale, though?

Mr. MINOGUE. The Mercalli scale is even less precise, because that's fundamentally a measure of earthquake damage. It's based on human observations and whether buildings fell down and people ran out or not. And that's not really appropriate to designing these very complex plants.

We're really in a level of design here that's far more detailed, because everything that you've been hearing about this morning relates to whether buildings fall down on people or not. And in our case, we're concerned about whether equipment continues to operate, because the objective is to keep the reactor from being overheated. That means that the equipment has to remain functional, and the design basis is quite different.

Mr. GORE. Is there no correlation between the size of the earthquake and the magnitude of the forces that you're trying to withstand?

Mr. MINOGUE. There is a correlation, but I——

Mr. GORE. But what size earthquake are you——

Mr. MINOGUE [continuing]. I cannot simply characterize it. I'm not able to characterize in a simple way. But there is a correlation, certainly.

Mr. GORE. Well, if there is a correlation, could you tell me what size earthquake most nuclear powerplants are designed with withstand?

Mr. MINOGUE. The G values for some of the older plants are as low as 0.1 G; the highest—and this is outside of my province, because I run the Research Office—I believe, is 0.6 or 0.7 G. Most of them are in the range 0.2 to 0.25. Certainly in the east coast plants, I think none is above 0.25, but I'm not 100 percent certain of that.

Mr. GORE. Maybe my question is unfair. If it is, I hope you'll explain to me why it is. But the question is, what size earthquake are nuclear powerplants designed to withstand? And your answer was that some of them are designed to withstand a G factor of 0.5. How big an earthquake does it take to produce a G factor of 0.5?

Mr. MINOGUE. It depends on site-dependent factors, the distance from the presumed epicenter and a number of other factors. It's not a direct correlation. And I simply can't answer the question in a simple straightforward way.

Mr. GORE. Which one has 0.5?

Mr. MINOGUE. The California plants typically are in the 0.5 and up range. And the east coast plants—I don't run the licensing department, Mr. Chairman. I'm not trying to avoid your question, but you're taking me into an area that's not in my shop.

Mr. GORE. OK, but the hearing—well—

Mr. MINOGUE. The east coast, I think—

Mr. GORE. But we called the hearing and asked you to testify about that in the first place.

Mr. MINOGUE. Yeah. I think the largest—to testify about the program to define seismic hazard, yes.

Mr. GORE. Yes.

Mr. MINOGUE. The—

Mr. GORE. Yes, and what I'm trying to do—

Mr. MINOGUE. I believe the largest G value for an east coast plant is 0.25 G but I'm not completely certain of that. That's used as a design basis. And that would roughly correspond to what you would get from the Charleston and New Madrid earthquakes, given the distances that you're from them. The closest plant to New Madrid, I believe, is something like 200 miles. The closest one to Charleston, I believe, is something like 100 miles.

Mr. GORE. Do you ask—in licensing, do you ask the question, how far is this plant from a 7.4—

Mr. MINOGUE. We require that historical earthquakes be considered. We also require that the seismology and structural geology be analyzed to determine whether there's a potential for earthquakes larger than the historical record.

Mr. GORE. Yeah.

Mr. MINOGUE. That's done on a basis that's largely regional. Within that region, lacking some indication of a cause for variations in seismic probabilities or seismic hazard, you would assume that the earthquake could be located anywhere within that region. If it's associated with a fault or some geological structure, the earthquake is arbitrarily assumed to move along that fault to the point closest to the nuclear powerplant site. That magnitude earthquake is then attenuated over the distances there and the type of materials. Site-specific factors are taken into account. All that ends up being translated into a set of synthetic time motion records or a

response spectrum that's used as the basis for design, and it then becomes vibratory motion input.

Mr. GORE. Yeah.

Mr. MINOGUE. The intent of this process is to define the largest earthquake that the region is capable of generating—

Mr. GORE. Yes.

Mr. MINOGUE [continuing]. Recognizing that there's some limiting factors that would affect the site in a conservative way.

What has changed over the years is this very good escalation in the knowledge and understanding of geologies. So we've had to go back and reexamine. That's why we have this extensive program in an area that's out of our normal—our normal scope.

Mr. GORE. All right. Well, let me—

Mr. MINOGUE. We have to go back and reexamine—

Mr. GORE. Let me go back and reexamine one question that I asked earlier. Is it true that some of the plants that were licensed early on are in areas where they may be threatened by earthquakes that you didn't previously think to be very real possibilities, but now appear to be.

Mr. MINOGUE. There's an indication of the need to reexamine the seismic design basis for the east coast plants, all of them. And that is being done. Threatened is a word I can't really accept, because if you look at the way the engineering design is done, the seismic design is not what determines the design of the structures at these relatively low G values. So if the G value were higher than you'd expected, you would see no effect of this, because other characteristics of the design would make them resist this G value. You would have to have very large increases. We've made studies to try to decide how much of an increase, and it's like factors of 3 or 4.

Mr. GORE. Is it possible that some nuclear plants now operating could be seriously damaged by earthquakes?

Mr. MINOGUE. In terms of a potential public hazard from malfunctions of the reactor, I think that the probability of that is very low. "Seriously damaged" could include also damage to power generating equipment.

Mr. GORE. Yeah.

Mr. MINOGUE. One of the earlier witnesses cited the damages to the Sylmar station in the San Fernando earthquake where a lot of switchyard equipment fell over.

Mr. GORE. Yeah.

Mr. MINOGUE. I couldn't speak to that.

But the stuff that relates to nuclear power safety, which is keep the core cool, I think there are very large margins in the present designs, if anything, they're overdesigned. We may have done better if we had made the designs simpler and not required so much in the way of seismic restraints.

Mr. GORE. OK. Well that answers my question.

Let me apologize again to all of you for having a hearing that lasts so long. We were interrupted by votes and the hearing lasted longer than I thought it would. But I appreciate your patience very much, and I want to thank you for your appearance here today.

And with that, the hearing will stand adjourned.

[Whereupon, at 2:15 p.m., the subcommittee was adjourned.]

EARTHQUAKES IN THE EASTERN UNITED STATES

WEDNESDAY, SEPTEMBER 12, 1984

HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND
TECHNOLOGY, SUBCOMMITTEE ON INVESTIGATIONS AND
OVERSIGHT AND THE SUBCOMMITTEE ON SCIENCE, RE-
SEARCH AND TECHNOLOGY,

Washington, DC.

The subcommittees met, pursuant to call, at 10:05 a.m., in room 2325, Rayburn House Office Building, Hon. Albert Gore, Jr. (chairman of the Subcommittee on Investigations and Oversight) presiding.

Mr. GORE. The subcommittees will come to order.

This is a joint hearing of the Subcommittee on Investigations and Oversight and the Subcommittee on Science, Research and Technology.

I'm pleased to join with my colleague, Doug Walgren, in chairing this hearing into earthquakes and the implications of earthquakes for public policy decisions, including those of the Department of Energy.

Earthquakes are not merely a west coast phenomenon. The most severe earthquakes in the contiguous United States occurred not in California but in New Madrid, MO, in the early 1800's. As recently as August 23, 1984, an earthquake of magnitude 5.2 on the Richter scale forced the shutdown of two nuclear reactors in Idaho. Thus, it is important that earthquake hazards be taken into account in the construction of lifelines and other structures throughout the United States.

Lifeline systems, such as oil and gas pipelines, which cross the Mississippi River in the New Madrid Fault zone, are very susceptible to seismic activity.

For example, if a significant earthquake occurred, not only could it disrupt oil and gas supplies in the Northeast, it could result in widespread damage from fires. Such destructive earthquakes are possible in this region.

Scientists have calculated that the stress currently built up in the New Madrid Fault, if released, would result in an earthquake of magnitude 7.6.

In addition, Dr. Arch Johnson of Memphis State University has recently estimated that there is as high as a 63-percent probability of a 6.3-magnitude earthquake in the New Madrid area before the year 2000.

The 1906 earthquake in San Francisco illustrates further the importance of seismic preparedness. That 8.3 magnitude earthquake caused extensive damage, but the major problems resulted from fire and human disease epidemics. These were the result of the disruption of the water supply and the loss of potable water.

More recently, water, sewer, and natural gas transmission systems were seriously damaged in the major earthquakes in Alaska in 1964, in the San Fernando Valley in 1971, and in Coalinga, CA, in 1983.

The great majority of existing buildings and other structures in the eastern part of the United States have not been specifically designed to resist earthquakes. Thus, in the event of a major earthquake, the damage to buildings and structures could be high, resulting in injury and loss of life.

Today's hearing, which is the second in a series, will explore the earthquake preparedness of the lifeline systems located in earthquake zones in the Eastern United States.

Witnesses from the Department of Energy and the scientific community will testify on the damages earthquakes might cause and on what additional research needs to be done to ensure earthquake-proof lifeline systems and other facilities in the East.

Let me add to this statement my own concern that decisions by the Department of Energy with respect to uranium enrichment facilities take fully into account the differing earthquake risks associated with different sites in the United States.

We intend to inquire in this hearing the extent to which these factors have been given adequate consideration in the planning decisions of the Department of Energy.

Now I want to recognize at this time my cochairman for this hearing, the chairman of the Subcommittee on Science, Research and Technology, Congressman Doug Walgren.

Mr. WALGREN. Thank you, Mr. Gore.

I want to express the appreciation of our members and the people who work with our subcommittee to the chairman of the Oversight and Investigations Subcommittee for his initiatives in this area of earthquakes.

The subcommittee which I chair has the authorizing jurisdiction over the earthquake preparedness program, and consequently it is most important for us to pursue the details that are developed by the oversight and investigations efforts made by Mr. Gore and his committee.

I think it's important for us to underscore how important we—the real importance that we place on earthquakes in the Eastern United States. We all know that earthquakes are sort of a difficult problem for the public to focus on because they don't happen every day and even more difficult in the East where the earthquake potential is less obvious. But having lived in the San Francisco Bay area, I know that there is a great tendency on the part of all human beings to repress what is a very real, and very present, and very overwhelming prospect of loss.

So we really want to focus on this as representatives of the public whose attention is at least brought to it by our public responsibilities and note that any scientific view of this is that the public in the Eastern United States is at risk as much, if not more

so, because of the density of population and the lack of awareness to direct loss from earthquake as is the public in California and other areas where there may be a very, very obvious and continued seismic activity.

We do invest a substantial amount in earthquake research. As always, we could do more, and I understand the evidence will be that we would benefit from doing more.

This Congress is spending about \$72 million on earthquake research. I think we have to take account of the fact that we, at least on the Federal level, are only spending about \$20 million on fire research and fire prevention of loss efforts. Fire is a very substantial threat to our public, and I raise that just to give us some measure to judge the effort that we make in this area.

I think that our total effort in emergency loss reduction on the Federal level is clearly inadequate, and we ought to be knowing that it should be strengthened across the board, and we ought to be judging our public policies based on whether it gives us the ability to strengthen those efforts across the board, because in this particular area the lack of effort can be traced directly into the loss of lives.

So with that, Mr. Chairman, I want to again say how interested our subcommittee is in following your efforts in this area and express our respect and appreciation for the initiative that you've taken to develop it in a public hearing forum. Thank you, Mr. Chairman.

Mr. GORE. Well, thank you very much, and it's always a pleasure to work with you.

Let me ask unanimous consent at this point that the statements—that a statement be included in the record from Representative Joe Skeen, who is ranking minority member of the Investigations and Oversight Subcommittee, and a statement from Representative Judd Gregg, who is ranking minority member of the Subcommittee on Science, Research and Technology.

I would also like to ask unanimous consent that my colleague from Tennessee, the Honorable Marilyn Lloyd, have her statement included in the record at this point and that she be given an opportunity to make her statement when she arrives at the hearing.

STATEMENT OF HON. MARILYN LLOYD, HEARING ON EARTHQUAKE VULNERABILITY—
SEPTEMBER 12, 1984

I thank my dear friends and colleagues, the Chairman of the Investigations and Oversight Subcommittee and the Science Research and Technology Subcommittee, for inviting me to participate in this hearing. It is a most timely one and holds particular significance to me as Chairman of the Subcommittee on Energy Research and Production, and Representative of the District that houses the uranium enrichment gaseous diffusion plant at Oak Ridge, Tennessee.

The Department of Energy will reach a decision next year on whether or not to close down one of the three gaseous diffusion uranium enrichment plants that it now operates. There are plants in Oak Ridge, Tennessee, Paducah, Kentucky and Portsmouth, Ohio. Eventually, I believe all of these diffusion plants will be closed down in favor of newer, more efficient technologies, such as advanced centrifuge or laser isotope separation. The question on close-down is one of timing; whether it will be sooner or later. If such a close-down is in the best interest of business in the near-term, then I will support it. However, thousands of jobs and lives will be affected by such a decision and all factors affecting the timing and selection of the first plant to close down must be carefully considered.

Of particular importance in this hearing is the vulnerability of the Paducah gaseous diffusion plant to an expected earthquake centered around the recently discovered New Madrid fault near the plant. If this plant does present an environmental, health and safety risk due to this newly discovered fault, that data will, of course, be factored into the decision making process.

This hearing, therefore, will help to identify a potentially significant problem at one of these three gaseous diffusion plants. I am hopeful that the DOE witness today will sufficiently define this problem and its potential impact on the enrichment program so that we may gauge its importance in the enrichment business.

I thank the Chairman and yield back the balance of my time.

Mr. GORE. Finally, I'd like to ask unanimous consent that Representative Carroll Hubbard of Kentucky will be able to put into the record a prepared statement of his own.

STATEMENT OF U.S. REPRESENTATIVE CARROLL HUBBARD

Mr. Chairman and Members of the Subcommittee on Oversight and Investigations, I had originally intended to deliver my remarks in person, but due to a scheduling conflict, I am unable to attend the hearing. However, I would like to request that my remarks be included in the official transcript of the September 12, 1984, hearing.

It is indeed a pleasure to have this opportunity to speak before the Subcommittee as the Member of Congress who represents western Kentucky and the gaseous diffusion plant located in Paducah, Kentucky.

The purpose of this hearing, as I understand it, is to examine the status of scientific data on the ability of structures in the Eastern United States to withstand earthquakes. Among those structures which I assume will be the focus of such data are the three gaseous diffusion plants located at Paducah, KY; Oak Ridge, Tennessee; and Portsmouth, Ohio. It is the question of earthquake potential in the Paducah area to which I wish to address my remarks today.

I have lived in western Kentucky for most of my life, and I can personally assure you that during those 40 some years, there have been no major earthquakes in that area. From this and the technical data provided to me by the United States Department of Energy I would surmise that western Kentucky, while carrying some risk of earthquakes, could be judged as having a very minimal earthquake potential in relation to other areas of the nation. Further, despite its location with regard to the New Madrid fault, I feel it is important to point out that according to Department of Energy officials, an earthquake in this area would affect not only the Paducah plant, but the plants at Oak Ridge and Portsmouth as well.

As we consider this question of earthquakes, it's also interesting to note the recent choice by the Democratic National Committee of San Francisco, a noted high risk area for earthquakes, as the site of the Democratic National Convention. Apparently, the threat of earthquakes was not a factor in finally choosing where hold the convention.

I realize, as I'm sure you do as well, that the Department of Energy is currently in the process of conducting a socioeconomic assessment study to determine the impact if they would be forced to close or curtail operations at one of the three gaseous diffusion plants located at Paducah, Oak Ridge, and Portsmouth. While I can appreciate the efforts of the distinguished Chairman to examine the ability of structures in this part of the United States to withstand potential earthquakes, and while I certainly recognize the need for examining this matter, I must also point out that there exists an element of timing in the holding of this hearing that cannot be ignored. Surely, any decision regarding the future of the three gaseous diffusion plants will not hinge on the outcome of this hearing today.

In fact, during my numerous discussions and meetings with Secretary of Energy Donald Hodel, at no point did the Secretary mention any concern about earthquakes, nor did he even raise the question. The subject of a potential earthquake hazard also failed to arise during my meetings with the Honorable Shelby T. Brewer, the Assistant Secretary of Nuclear Energy at the Department of Energy. Surely, both men would not ignore such a factor, if, in fact, it is of paramount concern. It would seem to me then, that the possibility of an earthquake at any one of the three gaseous diffusion plants needs to be considered, not alone, but in conjunction with the many other more critical factors for determining the fate of these plants, such as the economic feasibility and efficiency of continuing operations at each plant facility.

In closing, let me say that I, like everyone else involved with the three gaseous diffusion plants, look forward to the results of the socio-economic assessment study

by the Department of Energy in relation to the operation of the three plants. However, I sincerely hope that political considerations will not be an overriding factor in reaching the final decision regarding the possible closure of one of the plants.

Thank you for allowing my this time, and I appreciate your consideration of my comments during the course of your deliberations on this matter.

Mr. GORE. Now, let's begin the hearing with the first two witnesses—first three witnesses actually. First of all, Dr. William Hall, professor of civil engineering and head of the Department of Engineering at the University of Illinois.

We will just take them one at a time, I'm sorry. Come on up, Dr. Hall. Welcome. Please have a seat. We're not going to swear in witnesses today. If you could identify yourself to the reporter, though.

STATEMENT OF DR. WILLIAM J. HALL, PROFESSOR OF CIVIL ENGINEERING, HEAD, DEPARTMENT OF ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA, IL

Dr. HALL. Congressman Gore and Congressman Walgren, I am William J. Hall, as you said, professor of civil engineering at the University of Illinois, and head of the department. I'm pleased to be here today and to address the important subject that you're looking into.

Mr. GORE. Well, we're delighted to have you here, and we deeply appreciate your willingness to help us.

Without objection, your full prepared text will be included in the record. If you want to summarize any portion of it, feel free. If you prefer to present it, that's OK, too.

Dr. HALL. I would prefer not to read it. I'd like to paraphrase a few comments that I have in here—

Mr. GORE. Fine.

Dr. HALL [continuing]. And amplify these for you gentlemen, and at that point we can proceed with whatever questions you might have.

The subject of earthquakes in the East, of course, is an important subject and one around which many of us spend a good deal of our time.

In attempting to assess the earthquake hazard first of all—and I'm going to make a subtle distinction here between hazard and risk; I'd like to bring this out in a moment—we need to know as much as possible about the locations of earthquakes, and we have some idea of where past earthquakes have occurred in the east; the magnitude or measurement of the size of the earthquake, and you've had some geophysicists here to talk to you about this.

I would point out that a magnitude is a calculated number from a record and—although it's a measure of energy in a wave from an earthquake, as an engineer, we find that a magnitude by itself doesn't tell us everything, because you can have a large magnitude—Richter magnitude or other measure—of earthquake, and it can be very local, or if the duration of shaking is quite long, it can have other effects. So that number by itself is not completely indicative of what an earthquake can do.

We need to know something about the frequency of occurrence—

Mr. GORE. If I could interrupt you there—in other words, when they give the number measuring the magnitude of the earthquake, that in itself is insufficient to tell you how much damage will be associated with the earthquake—

Dr. HALL. Precisely.

Mr. GORE [continuing]. Because you have to also know what other factors?

Dr. HALL. We need to know other factors with regard to the intensity of the shaking as reflected by accelerations, and velocity, and displacement, and so forth.

Now let me back up. Obviously, if somebody gives in the news or there actually occurs an earthquake which they say is magnitude 7.5 versus another earthquake which is 5.5, you or I would immediately suspect that the larger magnitude would have associated with it more damage—that is a natural supposition—but it doesn't tell you the whole story.

Mr. GORE. Now when you go—isn't it true that on this scale, when you go up one number, you have actually magnified the intensity or the energy released——

Dr. HALL. Energy released.

Mr. GORE [continuing]. By a factor of 10?

Dr. HALL. I think I have to go back and—I think the energy released has gone up by a factor of 30, I believe—something like that—if you do some of the calculations.

Mr. GORE. Well, what is it that increases by a factor of 10?

Dr. HALL. I don't know; I can't answer that.

Mr. GORE. Well, I've got the wrong number then.

Mr. WALGREN. If the gentleman would yield, something increases by a factor of 10.

Dr. HALL. Sometimes it's a measure in terms of the ground displacement or numbers like this that might go up by a factor of 10 roughly, yes. That's not right, though. That's not correct either because—wait a minute; let's back up; let me get this straight.

I recently had occasion to testify, or give a talk, about—in relation to the nuclear power industry in margin studies. We were working on margins or what happens if larger earthquakes occur, and I—let's see; what did I surmise? I surmised with one increase in magnitude, the acceleration—I want to talk about this a little bit—the acceleration roughly doubled; it doesn't go up by a factor of 10.

Mr. GORE. Well, it was my understanding that on the Richter scale, the scale is logarithmic in nature.

Dr. HALL. That's right; it is, sir.

Mr. GORE. That when you go from 0 to 1, you have—when you go from 1 to 2, you have magnified by 10.

Dr. HALL. That's a decade in the logarithmic scale. We're using to the base 10; that's correct, sir.

Mr. GORE. OK; all right.

Dr. HALL. That's where the 10 comes from. It's measured on base 10. This is very technical, but we also have other kinds of logarithms——

Mr. GORE. Well, the point I'm trying to make is that it's not just an arithmetic——

Dr. HALL. No; it's a logarithmic scale; you're absolutely right.

Mr. GORE [continuing]. Progression, and the difference between a 6 and a 7 is far more significant than the numerals and the progression in those numerals might indicate.

Dr. HALL. That's a good statement. That's a very good perception.

Mr. GORE. The energy released is 30 times larger.

Dr. HALL. That's my recollection; on that order; that's right.

Mr. GORE. All right. Go ahead. I'm sorry to interrupt.

Dr. HALL. No; that's fine.

But the calculation becomes very complicated, because originally when Dr. Richter proposed the Richter magnitude, which is where this started—and I've heard him talk on it, and I know the gentleman—it just always talked about, as a point source for the earthquake.

Well, earthquakes are not necessarily a point source, because you have faulting that takes place, and I think you can see very clearly that this is along some length. So you sit here, and you say, well, where is that point source? Well, that's kind of hard to identify.

So there's some iffyness connected with this, is the point I'm trying to get across.

Let me go on. I think this will come out.

Mr. GORE. Sure.

Dr. HALL. So we have to get some measure of the shaking that goes with this earthquake and the potential for damage.

Now in the United States, and particularly in the eastern United States, these large earthquakes don't occur very often. We've had the New Madrid earthquake in 1811-12—three earthquakes actually—that you alluded to; we've had the Charleston earthquake, which was a pretty good size earthquake, in 1886, I believe; we haven't had them that often, and this is one of the problems in that our history of occurrence, and recorded occurrence, is not over a long period of time, as for example in China or Italy. So our basis for assessing what these earthquakes will do is limited.

This infrequent occurrence of these large earthquakes also leads the public to have an interesting perception about the earthquakes in the east. They don't see them very often, they don't experience them very often, so it's kind of a risk that's there, but maybe it isn't there because I haven't experienced anything, and that's one of the problems in the east, I think, that lack of a driving force.

You've made a statement about why the need for increased attention to earthquakes, and a good statement, in the sense that we have an increasing population, cities, numbers of cities, sizes of cities, much more in terms of industrial base that's exposed.

So this is a good point, to point out the distinction, as I would put it, between the hazard and risk, and you've got some other experts on the panel a little later that can address this.

But I always think of the hazard as being one of the earthquake, or the hurricane, which we're on the verge of, or fires, or whatever it may be. We can have a hazard which we can identify; in this case we're talking about earthquakes.

We need to know some of these parameters that I've talked about, and then we get into the things like, well, if the earthquake occurs, what is the intensity of shaking, or how often does it occur, and what's that—and what is it that it's going to affect, and this leads us into the risk aspect of it.

There is a subtle difference between the two in terms of assessing what the risks may be, so we can come back to that, if you wish.

People—as a result of this perception, people in the east—to repeat—I think, perceive the risk in many cases to not be very great just for the simple reason that they haven't been exposed to very many earthquakes in their lifetime, as contrasted to people in California who are subjected to earthquakes on a regular, frequent basis, and I am from California originally, incidentally, so I've been subjected to a number of them there.

I would comment briefly on the situation, or the wording that you used of earthquake-proof. As an engineer, I really don't quite understand what earthquake-proof means.

I've been party to designing lots of big systems, and I don't think I've ever designed anything that is, quote, earthquake-proof. I've designed—helped design many systems in which we have a high level of resistance to earthquakes—very high level of resistance to earthquakes, but I worry about the use of the word earthquake-proof.

We have made lots of advances in earthquake engineering, especially in recent years, as our database expands. This is in large part due to the very high level and funded programs in the National Science Foundation and the U.S. Geological Survey. These two programs of research have increased our ability to understand what's going on in the earthquake field and to do better things very significantly.

This has been driven, in part, by some of the considerations with regard to critical facilities. There's no secret about the fact that the nuclear power industry coming on the scene in the late 1950's, and 1960's, and 1970's was the driving force, in many cases, to put the pressure on in terms of doing this type of research, in the sense that these critical facilities needed this kind of input.

There are other projects, too—the Trans-Alaska pipeline, the proposed Alaska-Canada gasoline, the LNG facilities around the country, and on, and on, and on.

I've talked a little bit in my testimony about the critical facilities and indicating the nature in which information is brought into the mainstream of practice.

Those of us in this business have been party to some real advances, one of them being in the building structures field where, in the Applied Technology Council efforts, we've put out a document called ATC-3, which will have a big influence on building codes in the years to come, partly in detail, partly in philosophy, of what's included in them.

We've been through another exercise with regard to highway bridges, parts of this which are being incorporated in the bridge specifications nationally, incidentally—not just on the west coast but nationally.

We've just completed—several of us here today have been party to a very large study with regard to gas and liquid fuel pipelines. This document and its—is about to come about and will have a big influence in the practice there, put out by people who are not just scientists but many people who have actually designed these facilities.

So what I'm trying to point out here—and we could give other examples—is that progress is being made, very significant progress, in the engineering, design, construction arena, and this is encouraging and comes about from the concerted research effort that has been taking place.

There is another aspect that I alluded to in here, and I made this same point before Congressman Brown about 4 years ago. Some of us worked very heavily in the military systems also, and there is a direct correlation between work that's undertaken in the military systems and things that we do in earthquake engineering and so forth.

In military systems, we're looking at a different environment, but we're looking at the levels of resistance that must be provided for blast, and shock, and so on like this, and much of this information is used later and directly in the earthquake engineering field.

Now I'd like to make another point here in distinction. In order to simplify my thinking and perhaps to be of value to you in terms of how we approach these problems and the way we teach our students, I always like to think of these very complicated design, construction-related problems in the terms of loading and resistance, and if I could make a simple example here, the earthquake, which is over here, which may occur, leads to shaking of the ground, and this is the excitation or loading that is going to load this building or something. So it's an aspect of what the loading phase is. It could be winds from a hurricane and so forth that would be the loading phase.

Mr. GORE. Wait a minute. What do you mean, loading the building?

Dr. HALL. The wind blows on the building, so therefore it exerts a force on the building. So this is a loading on the building that the designers of this building had—

Mr. GORE. It's an increase in the stress pressures on the structural elements of the building.

Dr. HALL. Right; that's correct.

The designers of this building, first of all, built the building to perform a function, which is to have hearings and have offices and so forth. The building weighs a lot, so we have a lot of dead weight, in the sense of gravity, that the building must support.

At the same time, the designers, I'm sure, took into account what else could happen, and one of those things that's what else would be, well, what if we had high winds in Washington, DC? and I'm sure this was a part of their considerations in designing this building.

Similarly, if this building were in California—let's use that as an example—the designers, were it built today, would say, well, some of the other what-if's would be: "What if we had an earthquake?" and, "How big would this earthquake be?" and, "To what level should we base this design?" These are considerations that center, in this case, around the loading side.

Now, the engineers, at the same time, who are building this building are thinking about the type of materials they're building the building out of, how big the rooms are, what are the columns, what are the walls made out of, and so on and so forth, and these aspects deal with the resistance, if I can make the point now.

In other words, what is it that is inherent in this building that will resist the gravity forces, resist the winds, resist the earthquake's shaking, and this is really an interesting way that we look at it in terms of actually building a facility, whether it be a building, or whether it be a nuclear powerplant, or the Trans-Alaska pipeline, or whatever.

When you get down into the very technical aspects of designing a system, this is really one of the things that you're looking at.

We have made—briefly, we have made significant advances in building design. A question would be, "Why hasn't more of this technology been factored into the design process in the East?" I've addressed this briefly in the comments.

Partly it's from the perception of kind of a low risk. It partly has to do with economics in the sense that, because of this perception that the risk is low and designing for earthquakes will be an increment in cost of construction, I think there's been a reluctance on the part of people to factor this into the process.

But as I've pointed out in the last part of my testimony, I see signs of changes in the East, especially in those areas where there is—the hazard is recognized to be somewhat higher.

I think partly through education of people in the schools and partly through witnessing what's happened to critical facilities, partly through realization of what could happen in a big earthquake, there is a trend to start to become more interested in the codes and so forth in the cities in the State of Illinois where I come from, especially with regard to State buildings, to place more emphasis on seeing that State buildings, and hospitals, and things like this are designed to take account of earthquakes.

Now, with regard to lifelines—and we're getting toward the end of my statement here—lifelines are harder things to come to grips with, and you say, "Why?"

Well, several of us here in our testimony, and perhaps everyone in the end, has tried to classify what lifelines are, and this in itself is a problem in deciding what are lifelines.

I've given you several different descriptions here in terms of energy systems as regards pipelines, and communication networks, and transportation facilities, and water lifelines, and so forth, all of which come under that particular category.

We do know as engineers how to design these things, in some cases, to be more resistant to earthquake shaking. We still have quite a bit of research that really should and needs to be taken in this area.

To repeat slightly, much of our information at present is based on observations of how they respond in earthquakes on the west coast. In part it comes about from the efforts of designing some of these things in critical systems like nuclear powerplants.

In some cases we have information from the military systems, and it's kind of a slow process of identifying what they are and how we might approach these things.

It comes all the way down to equipment manufacturers. You have some of the large corporations that make equipment, and these, in essence, are also part of the lifeline infrastructure. Many of these lifelines inherently are quite strong just by the way

they're designed normally, even without consideration of earthquakes.

You made some mention about pipelines through the Midwest. As one who's worked in the pipeline industry off and on my entire life, a pipeline made out of a good quality steel with good quality welding is really a very tough system, and your concern might be more with the equipment that's at the pump station in places like this than it would be the pipeline running down through the countryside, frankly.

Now, when you go to something like Alaska, where we designed the Trans-Alaska pipeline, that's a different situation, and I don't think we need to discuss that in detail here, but in that case we were worried about the effects of warm oil flowing through a pipeline where there's permafrost and things like this with earthquakes and other things. So it had a lot of other things in it.

We do worry in lifelines about connectivity between elements. The supports that support equipment and so on like this sometimes in earthquakes show up to be the weak link; it's not necessarily the pump or the motor, it's how you fasten the pump or motor to the base and so forth.

We do worry about the foundation conditions for facilities where pipelines—where the lifelines are located. I, for one, coming from the Midwest, of course, have concern about the unconsolidated sediments along the big Ohio and Mississippi Rivers, where some of our industries are located, which could undergo liquefaction and spreading at the time of a big earthquake, as witnessed in 1811-12.

Now, to the credit of some of the industries that are located in those areas, some of them are quite aware of this. I personally am aware of some that have taken steps to mitigate what would happen in an earthquake, but that's probably an exception rather than the rule.

Now, I would finish by saying that in some respects in the earthquake field it's my perception that we have paid too much attention in the media and in our publications to the failures in earthquakes. These are valuable in terms of studying what can happen and to correct such deficiencies in the future.

I feel that we have not paid enough attention to the structures and lifelines that have not failed, and I would say unequivocally that in most earthquakes around which I've worked, the majority of things don't fail in a manner which affects the life and property in a major way, and you don't see much written on this, and you don't see much discussion about the things that didn't fail, and one of the things that some of us are pressing for is to pay more attention to this side of the ledger, to find out in more detail in our research why these items didn't fail.

So I would end with that particular comment. I think that summarizes my comments, Mr. Chairman. Go ahead.

[The prepared statement of Dr. Hall follows:]

Testimony of

WILLIAM J. HALL

to The Subcommittee on Investigation and Oversight
and The Subcommittee on Science, Research and Technology
of The Committee on Science, Research and Technology
of the
UNITED STATES HOUSE OF REPRESENTATIVES

September 12, 1984

My name is William J. Hall. I hold the positions of Professor of Civil Engineering and Head of the Department of Civil Engineering at the University of Illinois at Urbana-Champaign, Urbana, Illinois.

I appreciate being given the opportunity of testifying before these Subcommittees on the subject of Damage Projections for Future Eastern Earthquakes.

In attempting to assess the earthquake hazard in a region it is instructive to examine the occurrence of past destructive earthquakes as an indication of earthquakes yet to come. It is valuable to know as much as possible about their likely locations, magnitudes (size), frequency of occurrence (return period in years), expected intensity of ground shaking, and potential for damage. At present precise prediction is not possible so that assessment of future seismicity must be approximate at best.

The historical record of earthquakes in the United States extends back only 200 to 300 years, unlike the 2,000 or more years in China and Italy. As a result our hazard assessment must depend largely on the analysis of the occurrence of smaller, more frequent earthquakes. As for the eastern United States, three great earthquakes occurred in 1811-1812 near New Madrid, Missouri (the largest earthquakes to occur in the continental United States since settlement in early 1600) and another near Charleston, South Carolina in 1886.

Other significant earthquakes have occurred in the St. Lawrence region of Canada (near New England), along the eastern seaboard and in most interior states since the time of settlement. As pointed out by Dr. Otto Nuttli in his 23 May 1984 testimony to your Subcommittees, the eastern and central states can expect to experience earthquake damage in the future. This prediction is based in part on knowledge that transmitted earthquake energy is attenuated less in the East (East of the Rockies) than in the West, and damage can occur several hundred miles from a moderately large earthquake. For example, shaking from the 1811-1812 New Madrid earthquakes was felt in Chicago, Cincinnati and Washington, DC. It was reported (unofficially to me) that high rise buildings in Toronto, Canada responded to the effects of the modest July 1980 northern Kentucky earthquake, a not surprising observation to many of us. Research supported by the National Science Foundation, the U. S. Geological Survey, the Nuclear Regulatory Commission, and to a lesser extent by other groups, has begun at last to provide a data base for eastern United States earthquake studies. This

research in turn helps provide a basis for assessment of potential damage as well as a basis for improved siting, building and equipment design, and emergency operations procedures.

Why the apparent need for increased attention to earthquake hazard mitigation, and for that matter to almost all natural hazards (wind, tornados, hurricanes, floods, fires, as well as earthquakes)? In large part the reason lies with the growing population and associated physical plant (buildings, factories, facilities), wherein over a given area more people and facilities are exposed and thereby at risk than previously was the case. Accordingly a major earthquake today in all likelihood will cause more extensive damage (measured in loss of life, injury, and economic loss) than was the case a century ago. The foremost goal of earthquake hazard mitigation, of course, must be to reduce or preclude loss of life and injury to people.

Clearly, as in all facets of life on earth, some degree of risk must be assumed or accepted. It is economically, if not physically, impossible to provide a level of protection that will insure no loss of life, no injuries, and no physical damage. The problem then becomes one of deciding what is an acceptable level of risk, and perhaps even more difficult how to achieve this goal in a manner acceptable to society.

With this background then it is appropriate to review briefly the rapid advances in earthquake engineering that have been made in recent years, in spite of limited funding, and the reasons for these advances. From the standpoint of understanding ground motion the first strong motion acceleration data became available in the 1933 Long Beach, CA earthquake. The data bank increased slowly, but four well instrumented earthquakes in the time frame of 1971-79, and most recently data from Taiwan, have helped immeasurably in providing a better base for the required research directed to hazard assessment.

As research studies have progressed, changes in building codes occurred steadily but slowly. Military-related research on the analysis and strength of structures and equipment during and immediately following World War II provided a new dimension to an understanding of structural dynamics (studies of the loading and resisting behavior of structural systems), and provided a sound basis for much of the ensuing development in earthquake engineering, especially with respect to critical facilities. Thankfully this same transfer of technology between military and civil-related research is in progress today.

The driving force in earthquake engineering applications arose with the correctly perceived need to design and construct critical facilities based on modern earthquake engineering principles. Critical facilities can be of two general types, for example nuclear power plants, dams, offshore platforms, major pipelines, and LNG facilities, or alternatively hospitals and emergency services (including those on military bases), public safety agencies such as fire and police units, and certain lifelines such as waterlines, communication facilities, and access and evacuation routes. The process of development is well described in a section of Ref. 1 (p. 14) of which I am a coauthor and is repeated below.

"The results of basic earthquake engineering research ultimately find use in practical applications, though considerable time may elapse before the results are used fully. The way in which this research usually leads to practical application is as follows: the

owners, planners, and designers of special facilities, such as nuclear power plants, major dams, offshore drilling platforms, and high-rise buildings of fifty stories or more, usually recognize the advantages to be gained by making use of research results. They gather these results by reviewing technical publications and interacting with research workers. After critical facilities and high-technology projects have used these results, the state of the art works its way down to the design of ordinary engineered structures and facilities that are governed by building codes, industrial codes, and other standards. Finally, nonengineered structures, such as single-family dwellings, are affected through highly simplified requirements in building codes, which the builder follows without necessarily understanding why they are required.

The lag time for research results to be used in critical facilities is, typically, about one to three years. For research to be reflected in building codes and other codes usually takes on the order of five to ten years or longer. For nonengineered structures the lag time may be much longer."

Another distinct type of design application commonly occurs, especially in the case of equipment design, where the manufacturer, to meet code or contract requirements, will design, analyse and possibly test his component or assembly to insure that it meets the desired criteria. It is difficult at this time to document well these advances in application.

In the case of building type structures many significant design and construction practice related advances have occurred in recent years as a result of the research undertaken; even more advances of significance are in the offing as a result of recent studies. Future advances in this area will depend in part on obtaining a better understanding of the nonlinear behavior of structural systems as well as techniques for evaluating damage of deformed structures and the remaining margin of safety. Such studies are currently underway throughout the world but will take many years to complete in a manner that lends itself to practical design and code usage.

Lifelines are of many types. Lifelines of cities are commonly classified into four groups: energy systems associated with electricity, gas and liquid fuels; communications networks identified with telephones and telegraph, radio and television, mail and press; transportation facilities covering highways, railways, harbors, and airports; and water lifelines such as potable water systems, storm sewers and sewage and solid waste disposal systems.

Observations of lifelines performance in earthquakes suggest three typical kinds of possible associated disasters:

1. loss of utility service through failure of portions of the system, as well as financial loss, and loss of employment of the utility workers;
2. inability to cope with secondary effects such as fires and disease; and
3. failure of the system of such a nature that the lifeline itself becomes a hazard to life and property.

Fortunately the loss of life from such disasters has been relatively light in recent earthquakes.

Last, but by far not least, is the matter of education of students and professionals in this important area. Improved design and constructions practice, implementation and enforcement of building codes, and emergency operations will be possible only with individuals properly educated.

Finally, again, what about the East? Except in the case of critical facilities and enlightened high-technology firms, the adoption process of hazard-reducing construction is slow. In large part this slowness is brought about by the perception of low risk. And, in such a case, economics clearly dictates the direction taken by designers and builders. There are exceptions of course, but they are rare. On a more optimistic note there are signs of progress, as slow as it may seem. Some cities and states, as for example Boston and Illinois, have adopted a building code with earthquake provisions. In the Mississippi and Ohio valleys I perceive an increasing awareness of the potential hazard posed by a great earthquake, and the states are starting to introduce codes that include earthquake provisions. Engineering and architecture groups are beginning to center programs around the subject. In time this awareness will find its way into practice, especially as those educated in modern design assume responsibility for new design and construction. This process will be expedited in turn as public officials become more knowledgeable about natural hazards of various types, their potential for loss of life, injury and damage, and steps that can be taken to mitigate the effects of such hazards.

Thank you.

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BIOGRAPHICAL DATA

William J. Hall
(Revised 09-05-84)

William J. Hall, Professor and Head of the Department of Civil Engineering at the University of Illinois, Urbana, Illinois, has been a member of the faculty at the University since 1949. During this time he has been engaged in research and instruction in structural engineering, structural dynamics, earthquake engineering and materials.

He was born on 13 April 1926 in Berkeley, California. After attending the University of California at Berkeley in 1943 and 1944, he entered the U.S. Merchant Marine Cadet Corps and served in the Pacific War Zone and at Kings Point until 1945. He received the degree of Bachelor of Science in Civil Engineering from the University of Kansas, Lawrence, Kansas, in 1948. While a senior student he held a teaching assistantship and worked summers for the Kaw Valley Drainage District and the Phillips Petroleum Company Kansas City Refinery. Upon graduation he received the ASCE Kansas Section Award for the Outstanding Civil Engineering Graduate of 1948.

In 1948 and 1949 he worked as an engineer in the field and operations sections of the Sohio Pipe Line Company, a subsidiary of the Standard Oil Company of Ohio. He joined the staff of the Civil Engineering Department, University of Illinois in 1949, holding successively the positions of Research Assistant (1949-52), Research Associate (1952-54), Assistant Professor (1954-57), Associate Professor (1957-59), and Professor of Civil Engineering from 1959 to date. He undertook graduate study at the University of Illinois and received the degrees of Master of Science in Civil Engineering in 1951 and Doctor of Philosophy in Civil Engineering in 1954.

He received the A. Epstein Memorial Award in 1958, the Walter L. Huber ASCE Research Award in 1963, the Adams Memorial Membership Award of the American Welding Society in 1967, the Halliburton Engineering Education Leadership Award of the University of Illinois College of Engineering for 1980, the 1984 ASCE Newmark Medal and the 1984 ASCE E. E. Howard Award. He was appointed an Associate Member of the Center for Advanced Study, Graduate College, University of Illinois for 1963-64.

In 1968 he was elected to membership in the National Academy of Engineering and in 1979-80 served as Chairman of the Membership Committee.

At the University of Illinois his duties have involved teaching and research in structural engineering and structural mechanics; he carried major departmental responsibility for graduate student and research affairs (1958-73) and serves on many high-level university policy committees and boards. Recently he chaired the Research Management Advisory Committee of the Graduate College at the University of Illinois and is a member of the Advisory Board of the University of Kansas C.E. Department. Specific areas of formal research have included such topics as fatigue machine design; effects of blast forces on model submarine hulls; design, construction, and test operation of protective structures at the AEC Nevada Test Site; static and dynamic response of beams and connections; shear strength of steel beams; brittle fracture behavior of welded steel plates; properties of metals under static and dynamic loadings; seismic hazard evaluation and earthquake engineering. He is currently principal investigator of a large research program sponsored by the National Science

W. J. Hall - Biographical Data (Revised 09-05-84)

Foundation in the area of earthquake engineering with application to improvements in analysis and design of structures and equipment.

He is the author or co-author of over 140 formal publications (books and articles) in the fields of structural engineering, structural mechanics and dynamics, soil dynamics, earthquake engineering, plasticity, fatigue, brittle fracture mechanics, civil defense and education. He is the co-author with H. Kihara, W. Soete and A. A. Wells of a book entitled "Brittle Fracture of Welded Plate" published by Prentice-Hall in October 1967. In addition he is the author or co-author of over 150 major consulting reports, many of public record and wide distribution.

He serves (or has served) as a consultant to a number of industrial organizations and governmental agencies, including for example the U. S. Army Office of the Chief of Engineers, the U. S. Army Waterways Experiment Station, the U. S. Army Construction Engineering Research Laboratory, Naval Civil Engineering Laboratory, the U. S. Navy Bureau of Ships, Stanford Research Institute, Union Carbide Corporation, Alyeska Pipeline Service Co., Foothills Pipelines, Inc., Western LNG Associates, TERA Corporation, Dupont, EG&G - Idaho, and Lawrence Livermore Laboratory. On his own, and as an associate to N. M. Newmark until 1980, he has carried major consulting engineering responsibility for projects in such areas as development of design criteria for hardened protective structures including missile facilities, physical vulnerability studies, vibration studies of missile test stands, reactor containment structural design and analysis, nuclear field test studies, review of structural criteria and designs for nuclear power plants and equipment for seismic loading for the U. S. Atomic Energy Commission and the Nuclear Regulatory Commission, and development of seismic design criteria for the uranium hexafluoride gas centrifuge plant. He has been a principal consultant since 1970 on the trans-Alaska pipeline and during 1980-83 on the Alaska-Canada gas line and the Western LNG Terminal at Point Conception. Also he is the senior advisor on a panel of the Defense Nuclear Agency.

In 1982 he served as a member of the Defense Science Board Task Force on Closely Spaced Basing for M-X, the Townes' Committee, reporting to USDRE and The Secretary of Defense, DOD. Currently he is a member of the Nuclear Hardness and Survivability Review Group (so-called Haas Panel) reporting to the Commander of the Ballistic Missile Organization, USAF.

In 1964 he participated in Project HARBOR, a study of the national civil defense posture, and in 1967 participated in the Little Harbor review. In 1964 he was selected as one of the five U.S. scientists and engineers to participate in the first Seminar on Brittle Fracture held in Tokyo, Japan under auspices of the U.S. - Japan Cooperative Science Program. In 1965 he was selected as one of 30 scientists and engineers to participate in the Meet Modern Sweden science tour held under auspices of the Royal Swedish Academy of Science and Royal Swedish Academy of Engineering. In 1966 he served as a member of the Commerce Technical Advisory Board Panel on High Speed Ground Transportation and was Chairman of the Panel on Guideways, Suspension, and Aerodynamics. From 1970 to 1973 he was Chairman of the Materials and Fabrication Subcommittee of the Ship Research Committee, NRC. In 1974-76 he served as Chairman of the NMAB Ad Hoc Committee on Application of Fracture Mechanics Analysis Techniques to Marine Systems. From 1974-77 he was a member of two committees (seismic ground motions, and structural design provisions) of the ATC-3 project of the Applied Technology council, a group working to develop national comprehensive seismic design provisions; also, he was a member of project ATC-6 studying the seismic

W. J. Hall - Biographical Data (Revised 09-05-84)

design of bridges. Currently he is a member of ATC-10 charged with developing new approaches to characterization of earthquake ground motion for use in design. In 1975-76 he was a member of the Panel on Earthquake Prediction of the NRC Committee on Seismology. He was a member of the Committee on Seismology, NAS/NRC in 1976-1979 and was Chairman of the NAS/NAE/NRC Committee to provide recommendations for improving the siting of critical facilities; he is currently a member of the National Research Council Committee on Earthquake Engineering. He was a member of the Earthquake Hazard Mitigation Advisory Committee, National Science Foundation (1979 to 1983). He was also a member of the Earthquake Studies Advisory Panel (1981-83), U.S. Geological Survey, Department of the Interior.

He was a member of the U.S. delegation on Earthquake Engineering and Hazards Reduction that visited the People's Republic of China in 1978 under auspices of the National Academy of Sciences.

He is active as officer and member of many professional and scientific groups and societies: Fellow, American Society of Civil Engineers; Member, Structural Division Executive Committee, 1971-75 (Chairman 1973-74); Chairman, Structural Division Research Committee, 1960-64; Awards Committee 1975-79; Member and past Chairman, Committee on Plasticity, EMD; Member, Committee on Dynamic Forces, and Committee on Nuclear Structures and Materials, 1975-79; Member, Committee on Gas and Liquid Fuel Pipelines, TCLEE, 1976-; Member and past Chairman, Executive Committee TCLEE, ASCE, 1980-Present; Secretary-Treasurer, Central Illinois Section, 1956-59; Vice President, President and Director, Central Illinois Section, 1965-68; Fellow, American Association for the Advancement of Science; Earthquake Engineering Research Institute (Director 1981); American Concrete Institute; American Society of Mechanical Engineers; American Welding Society; American Society of Engineering Education; the International Institute of Welding; 1959-74, Expert on IIW Commissions IX and X; Seismological Society of America; American Society for Testing and Materials; Society for Experimental Stress Analysis; International Association for Bridge and Structural Engineering (Reporter, 1968); Illinois Society of Professional Engineers; National Society of Professional Engineers; Structural Engineers Association of Illinois (Chairman of Seismology Committee, 1973-77); Honorary society memberships include Tau Beta Pi, Sigma Tau, Phi Kappa Phi, Sigma Xi, and Chi Epsilon. He is an editor for a series of texts in civil engineering and engineering mechanics for Prentice-Hall, Inc.

He is a Registered Structural Engineer and Professional Engineer in the State of Illinois, and is a Registered Professional Engineer (Civil) in the State of California. He is listed in Who's Who in America, Who's Who in the Midwest, Who's Who in Metals, Personalities of the West and Midwest, American Men of Science, Engineers of Distinction and Who's Who in Engineering.

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Mr. GORE. Thank you very much for getting us off to a good start. We'll ask some questions now.

Our next witness is going to be from the Department of Energy, and we'll get into some specific cases there, but you have given us a good overview of how the building industry generally, and those who build things like pipelines and other structures, take earthquake risk into account.

How widespread—is it fair to say that the earthquake risk data is more widely used in the construction of major facilities in the West than it is in the Eastern United States—in California than in the Eastern United States?

Dr. HALL. Well, let's see. That question requires several answers; it's a good question.

It depends on what you're talking about. If we are talking about in this day and age today—now, you have to balance this off again against what's happened in the past—I think that any responsible group or corporation who is building an item that I would call a critical facility—classified as a critical facility today—would be very conscious of the effects of natural hazards in the design of that facility, no matter where it's located, East or West.

The perception that you put across is of course true on the west coast for the simple reason that the earthquake hazard is more obvious, and so therefore it's addressed in the press more, and so forth, so it's something that's there. But my personal opinion is that in critical facilities—and I've been associated with a good many of these across the United States—it's brought into the process no matter where it is in the United States.

Now, if you come down a level to things like routine industrial construction, or housing, West versus East, you're absolutely right, there is more attention to this in the West than there is in the East; it's at a different level down the line, partly for the reasons that I alluded to in my testimony; you're correct there.

Mr. GORE. OK. So as we get a clearer understanding of the risks associated with the New Madrid Fault, we should see a greater awareness of the need to take that risk into account for the construction not only of facilities you term critical but also for other large facilities that could be damaged seriously in an earthquake.

Dr. HALL. Yes, I think that's happening. But I would add one statement. I made a little piece of my testimony centered around risk and human life, pointing out that all of us walking down a street or driving a car accept some level of risk on a daily basis, and from that point of view and an economic point of view, I think it has to be very carefully measured what we do.

The answer, of course, I would say, improvements can be made. I mean I'm trying to answer your question directly. Improvements can be made and should be made over what we do now, and I'll let you go.

Mr. GORE. Are there areas in the Eastern United States that you would single out as being very good in the use of earthquake data and construction and other areas that you would say have a long way to go in the use of such data?

Dr. HALL. Well, as I spoke to a minute ago, this is a changing situation. Certain States have taken steps to see that the buildings, for example, that are funded by State moneys have this provided.

Some cities—I'm reminded of Boston; I think I referred to it—Boston has adopted a code which takes earthquakes into account.

There seems to be an increasing awareness in the St. Louis—and I can't speak for Memphis; I've got to go speak in St. Louis in a few weeks, so I know they're becoming more conscious—

Mr. GORE. There is an increasing awareness in Memphis as well. I've been there and have discussed it with several people there. But both Memphis and St. Louis, of course, are very near the—how about Paducah?

Dr. HALL. I haven't—I can't speak to Paducah, because I haven't had much to do with Paducah, so I can't—it's on the Ohio River and, obviously, in an area that one would need to think about the problem, very clearly.

Mr. GORE. In other words, it's—

Dr. HALL. Well, it's close to Memphis and—

Mr. GORE [continuing]. Right on the New Madrid—right in the New Madrid risk area.

Dr. HALL. It's in that zone; that's correct.

Mr. GORE. Is additional research needed in order to provide more accurate data for construction use?

Dr. HALL. The answer is "Yes."

Mr. GORE. All right. I have some other questions, but let me hold up on them and turn to my colleague, the cochairman of the hearing, Doug Walgren.

Mr. WALGREN. Thank you, Mr. Chairman.

Just to raise some—pursue some thoughts that your testimony raised, you mentioned the increased awareness in codes of building construction and in bridges. What kinds of things are we anticipating to do in these building codes, and how much does that cost in adding to construction? Can you just give us some general outline of what specifically we are talking about in that area?

Dr. HALL. In terms of the costs, sir? Is that what you are referring to?

Mr. WALGREN. Yes. Just to give somebody who has absolutely no idea what the specifics of the construction industry are, what are we talking about?

Dr. HALL. Well, I'm not—I am a structural engineer, but I don't on a daily basis produce design drawings—let's put it this way—but I have been around these kinds of studies, of course.

For moderate levels of increases in seismic resistance, in standard structures, I would say industrial structures and routine bridges and things like this, in terms of the increment of cost, in terms of design and construction, you hear numbers ranging from 6 to 8 percent up to 20 percent, in this range. Sometimes the numbers are quite low; sometimes they're higher. Now let me tell you why.

The reason for this is the following: In those cases where things are being designed by engineers who are educated in this field, some of this practice is routine, it just comes naturally, and it's easy to incorporate it in design, and it kind of comes naturally.

In other cases, though, where the complex may be more complicated in nature, or you have to bring in a special group to do this, or you have to use special materials for certain facilities, then the increment is larger, of course.

So it's kind of—your question is a very good one, but it's kind of hard to put a specific—specific number on it. Clearly, it will be more, but my perception is that when carefully handled, the increment, in some cases, is not—is not that much more.

Now, if you are going to talk about a larger—you have to be careful now; I should qualify this—if you are going to talk about resistance for a very, very large earthquake, then that would have to be a decision that would be made, whether you wanted to design your plant for an earthquake that might occur once every 500 years, or 300 years, that would have to be a very definite decision that you make. If you want to factor that into your facility, that will be a bigger increment, clearly; it could be a very large increment; but I might raise a question as to whether that was a wise decision.

Mr. WALGREN. Yes. But the general cost to strengthen it against more frequent stresses would, you feel, be not even a specific decision at this point? Is that your feeling?

Dr. HALL. Well, no. It would take a specific decision, but it would be if you have people in your firm who are educated in this area, structural dynamics—it would be easy to incorporate.

You would find it an easy thing to incorporate the adequate bracing or the shear walls or whatever is required to give the structure the added resistance, and there will clearly be an increment in cost. I mean it's going to be more material, there's going to be some more details.

What I'm saying is that it may not be all that much greater because realize, first of all, if these people are doing their job as I think they probably would be doing it, they're already designing the building for some rather high level of wind resistance, and, in some respects, there is a parallelism in the resistance picture between the winds that we design for in the Midwest and the shaking that goes on with earthquakes.

Mr. WALGREN. I see.

You mentioned the nuclear power industry. Historically, when the nuclear power industry started, did they take adequate account in the siting guidelines of the possibility of earthquakes?

Dr. HALL. Well, I can't speak before 1964. My association with the nuclear industry started in 1964, and I can speak straightforward about that. At that time and thereafter, the answer was yes—as well as they could; let's put it this way.

Mr. WALGREN. Uh-huh. How do you—what's your view of the earthquake resistance ability of the initial nuclear powerplants that are presently operating in this country?

Dr. HALL. Now, well, let's be clear what we're talking about. You mean the ones that were built in the 1950's, or are you talking about the ones that were built in the 1960's and 1970's?

Mr. WALGREN. Well, is there a dividing line in there?

Dr. HALL. Oh, sure, there's a big difference. I mean as the industry, and the research that was undertaken, and the awareness of earthquakes, and the perception of what the public—the risk was to the public, and so on, there was a quantum leap in concern for earthquakes in that period of time.

Mr. WALGREN. And when did that quantum leap take place?

Dr. HALL. I'd say starting in about the very late 1950's into the early 1960's—into the mid-1960's.

Mr. WALGREN. And how would you describe plants before the quantum leap and plants after the quantum leap?

Dr. HALL. In those few cases where I've had occasion to review plants after the fact, that were designed in those early days, there was consideration of earthquakes, absolutely, but it was at a level which was commensurate with the building codes at that time.

Mr. WALGREN. And then what did they do afterwards?

Dr. HALL. In many—most cases, they've retrograded—upgraded them; very expensive; very costly.

Mr. WALGREN. Is there any way to judge whether a present plant or one of the previous ones are retrofitted or improved—what level of earthquake exposure you would feel comfortable with?

Dr. HALL. Well, I don't know about the feel comfortable with, but the answer is yes. What you do is go in and make a very, very detailed study of the building, and the equipment inside, and so forth. It can be done, and it is done; yes, sir.

Mr. WALGREN. And what level of earthquake are they—are you satisfied that they are able to withstand?

Dr. HALL. Well, it depends on the location of the facility and what its function is. I mean that's—I can't answer that specifically because it depends on where it is, what its function is, what are the possible modes of failure, what effects these would have, and so forth. It requires a special study.

I'm not trying to be evasive. It's just—

Mr. WALGREN. Have such special studies been made?

Dr. HALL. On many of the reactors—if you are talking about power reactors, certainly; the answer is yes, and I've been part of these. I mean I could speak to—I've been part of these; sure; in many cases; not all cases but many cases.

Mr. WALGREN. Thank you, Mr. Chairman.

Mr. GORE. Mr. Skeen.

Mr. SKEEN. Thank you, Mr. Chairman.

Dr. Hall, I've enjoyed listening to your testimony here and then reading the summary this morning.

Having survived the 1933 Long Beach earthquake, it's always been a lifelong interest to me. I went to school in the second grade in a tent city in Los Angeles after the—as an aftermath of that catastrophe, and I just—I wonder, Doctor, as an engineer, is there any cyclical predictability to earthquakes? Have we identified all the major fault lines and things of that kind? Just how far have we progressed in the science?

I noticed in your statement here that the Chinese and the Italians have probably got 2,000 years of history, and we've done something in the last 200 to 300 years. How far advanced and how current are we in that sort of scientific investigation on predictability, and identification of stress areas, and things of that kind?

Dr. HALL. Well, first of all, I'm not a geophysicist—you have to recognize this—and my field of expertise—

Mr. SKEEN. Just being an engineer is all right; geophysicists are secondary.

Dr. HALL. Well, I appreciate both sides, Congressman Skeen. I think we've made great strides. You really should be asking that

question to somebody from the Geological Survey perhaps, but from an engineering point of view we've made great strides, and in those areas of the country, namely, California—I'm also raised in California, incidentally.

Mr. SKEEN. I noticed you're from Berkeley.

Dr. HALL. That area, right.

Mr. SKEEN. Yes, sir.

Dr. HALL. And where we have a number of earthquakes of significance, the studies that have gone forward, I think, have helped immensely in identifying the active faults and so forth.

Now you never get all the active faults, as we witness things happen here and there, and California, where they didn't exactly predict something was going to happen, but it's certainly better than it was 30 years ago or 40 years ago.

In the East, we're not as well off with the—in general, the mantle that covers the basement rock and so on, as Dr. Nutley talked about here before you, in the sense that most of these faults don't come to the surface, but, again, through observations, I think, and studies of the micro-seismic activity, we're getting an increased appreciation of the activities at certain locations around the country, but this is time-consuming and expensive, it takes a lot of people and a lot of study, but progress is being made. I don't know how else to answer it.

Mr. SKEEN. Well, the reason I ask you that question, Doctor, is because, as an engineer, I was interested in your response mainly from the idea of just how much background and just how comfortable our designers and engineers and the rest, with the database, and just how accomplished are we insofar as institutions of education or educational institutions, in the studies—ongoing studies and so forth for the kinds of design criteria that you're going to have to use—our engineers will have to use, and designers would have to use. I was just curious as to what kind of dedication we have, say, nationwide in this particular area or problem area.

Dr. HALL. Well, that's a very good question. As an engineer, I'd say, first of all, in my years of practice, we use whatever information we have available at that particular time, and in my span of practice, of course, we've got an increasing base of information, and each time you do something, you use it. So the first thing is, it gets better, and better, and better as we get—

Mr. SKEEN. It has improved then, in your opinion?

Dr. HALL. Oh, certainly, and our database, as I pointed out kind of briefly in my testimony—when San Fernando earthquake occurred February 1971, our number—amount of instrumental data doubled overnight, for example.

Mr. SKEEN. Sure.

Dr. HALL. And that was a tremendous help to those of us who are studying what effects the earthquakes have and so forth.

In the schools—I come from one of the schools which is very strong in structural dynamics and related things—we work in this area heavily there at Berkeley. The California—many of the California schools are heavily involved, and MIT, and so forth, but other schools—and for good reason.

We don't have research programs like we do in things like this, but that doesn't mean it isn't taught as part of the structural curriculum that a student would have.

So most—I would say that most students who go through the better schools in the United States today are getting exposed to this more than they did 20 or 30 years ago, I might say perhaps not as much as they should.

Mr. SKEEN. Let me hold you right there—interrupt you just a minute, Doctor, and say that what you're saying is that the database is pretty good, the response where you have an acute interest is very good—

Dr. HALL. Right.

Mr. SKEEN [continuing]. But it's not a universally accepted criterion on which to do design and engineering.

For instance, in schools that teach engineering or architectural engineering classes, it's—in some areas, it's overlooked, if you don't have an acute point of interest—focus of interest, such as you would at Berkeley or someplace else.

Dr. HALL. I think that's a fair statement, sir.

Mr. SKEEN. That's very interesting, because I would think that—I notice we talk a lot about utilities and pipelines and so forth, and we're becoming more and more dependent as a nation on these kinds of networks and utilities, and I would think it would be one of the basic considerations for any engineering or design criteria, and I'm a little astounded that maybe we don't take that into consideration and—

Dr. HALL. Well, now, I wouldn't say we don't take it into consideration. The statement I made was that I don't think in many cases it's taken into consideration as much as it should be taken.

Mr. SKEEN. I see.

Dr. HALL. And there are changes. The point I want to make is, things are changing, and they're changing for the good.

Mr. SKEEN. Thank you very much, Doctor, and thank you, Mr. Chairman.

Mr. GORE. Mr. Boehlert.

Mr. BOEHLERT. No questions.

Mr. GORE. Well, Dr. Hall, I want to thank you for getting us off to a good start with this overview of how engineers take earthquake risk data into account in designing structures.

You're known as probably the leading authority in this country on that specific area of knowledge, and we greatly appreciate your willingness to come and share it with us and to get us off to a good start this morning.

Dr. HALL. It's been my pleasure, sir.

Mr. GORE. Thank you.

Our next witness—our next two witnesses will come together, please, to the witness table: John R. Longenecker, deputy assistant for uranium enrichment and assessment at the Department of Energy; accompanied by Dr. James E. Beavers with the Martin Marietta Corp.

We're delighted to have both of you here. Without objection, your prepared statements will be included in full in the record. You're invited to proceed with them at this time, and we'd like to begin with you, Mr. Longenecker.

STATEMENT OF JOHN R. LONGENECKER, DEPUTY ASSISTANT SECRETARY, URANIUM ENRICHMENT; DEPARTMENT OF ENERGY, WASHINGTON, DC, ACCOMPANIED BY DR. JAMES E. BEAVERS, MARTIN MARIETTA CORP.

Mr. LONGENECKER. Good morning, Mr. Chairman.

Based on discussions that we had with your staff, I will be addressing today only the potential seismic effects on the Department of Energy's gaseous diffusion plants.

Now, it is clear from your letter to Secretary Hodel that you may desire additional information on other DOE facilities, and if you do, we would be pleased to submit that information for the record.

Mr. GORE. Fine.

Mr. LONGENECKER. Proceeding then with the topic of discussion today, Mr. Chairman, the U.S. Department of Energy operates three gaseous diffusion plants at Portsmouth, OH; Paducah, KY; and Oak Ridge, TN.

Mr. GORE. Do you have copies of your prepared statement, incidentally?

Mr. LONGENECKER. I do not have a prepared statement. I'm—I'm going to provide some overview remarks, and the details of the seismic analysis of the gaseous diffusion plants will be presented by Dr. Beavers.

Mr. GORE. OK. But you don't have copies of your remarks for the subcommittee?

Mr. LONGENECKER. No, sir.

Mr. GORE. OK. Well, go ahead. Normally we like to get those. It's all right, but go ahead.

Mr. LONGENECKER. Yes, sir. Because of the time in which we received the request, we were not able to prepare and clear—

Mr. GORE. OK. Please proceed.

Mr. LONGENECKER [continuing]. Testimony.

The three gaseous diffusion plants that we operate do provide enriched uranium for nuclear power reactors in the United States and in other foreign countries, primarily the Far East and Europe, and we also provide enriched uranium for national defense needs.

DOE is currently the world's largest supplier of enriched uranium, and all of our production comes from the three existing gaseous diffusion plants. These plants were built in the 1950's and comply with all applicable design guidelines that were in existence at that time.

Although the GDP's could operate reliably into the next century, future use of them may be limited by their economic competitiveness, primarily due to the power intensity of the gaseous diffusion process.

Accordingly, DOE is now developing two alternative, potentially lower cost technologies, the advanced gas centrifuge and the atomic vapor laser isotope separation process, for potential deployment at some time in the future.

We are evaluating at the same time, as you noted in your opening remarks, what mix of those three technologies we should operate to meet our customers' needs in the most reliable, cost-effective manner possible.

We are also constructing a new facility embodying the gas centrifuge technology in Portsmouth, OH.

All new DOE facilities, including this enrichment facility—and it's called the Gas Centrifuge Enrichment Plant, or GCEP—are being designed to withstand seismic impacts. The DOE requirement that we have agencywide to consider seismic effects in facility design is contained in the Department of Energy's general design criteria 6430.1 and has been applied to the design of all DOE facilities since the mid-1970's.

I would note also that we have used seismic design codes and generally accepted building codes since the 1960's which include seismic design criteria in them.

Now in determining in what mode and for how long we're going to operate the three existing gaseous diffusion plants, the department is evaluating several key factors that affect the enrichment complex. These factors include the ability, first of all, to meet the customer demand and the demand of the defense community in the United States; the relative economics of the various means of enriching uranium; and a number of other factors, including the potential effects of natural phenomena.

As a portion of our study as to how we operate the complex in the future, we're in the process of evaluating the response of the gaseous diffusion plants to a number of physical phenomena, including seismic events.

Here with me today is Dr. James Beavers from the Martin Marietta Corp. Martin Marietta does operate for us the Oak Ridge plant as well as the Paducah plant. Dr. Beavers will discuss for you the design of the gaseous diffusion plants and then the recent seismic analysis that we have conducted.

Mr. GORE. All right. Thank you very much.

Dr. Beavers, we're delighted that you're here, and we look forward to your statement, so please proceed.

Dr. BEAVERS. Thank you, Mr. Chairman.

I would like to stick to my prepared statement.

Mr. GORE. Fine.

Dr. BEAVERS. The Department of Energy's uranium enrichment facilities were designed and constructed in the early 1950's in accordance with specific design criteria. Although, to the best of my knowledge, no seismic design considerations were given to the Oak Ridge or Portsmouth gaseous diffusion plants, some consideration was given to the Paducah gaseous diffusion plant.

Existing documents reveal that in 1950 discussions occurred whether to design the Paducah gaseous diffusion plant for seismic zone 3 requirements. The Paducah area had been included in the seismic zone 3 that surrounded the New Madrid region in the publication of a seismic probability map of the United States by the U.S. Coast and Geodetic Survey in 1949.

In 1952 the Pacific Coast Building Officials adopted this map into the Uniform Building Code, a map which the U.S. Coast and Geodetic Survey withdrew that same year.

After considering the necessity for designing the Paducah plant for seismic zone 3 requirements, the documents show that the decision was made to check the facilities' resistance for seismic zone 1.

It was concluded that forces attributed to other dynamic and static loadings apparently were the controlling factors in the design.

Mr. GORE. If I could—well, go ahead—finish that next sentence, and then I'll interrupt.

Dr. BEAVERS. The prevailing view in the Eastern United States was that wind load criteria generally provided a large degree of seismic resistance for building structures in seismic zone 1.

Mr. GORE. Yes; excuse me for interrupting, but I don't quite understand. Seismic zone 3 and seismic zone 2 are terms that measure the level of risk within particular geographic areas; is that right?

Dr. BEAVERS. Yes, that's correct.

Mr. GORE. Now, is the risk higher in zone 3 than in zone 1?

Dr. BEAVERS. That is correct.

Mr. GORE. OK. Now, at the time the enrichment facility was constructed in Paducah, the available evidence indicated that the plant was located in seismic zone 3; is that right?

Dr. BEAVERS. That is correct.

Mr. GORE. However, for some reason, the decision was made to build the facility as if it were located in seismic zone 1; am I correct there?

Dr. BEAVERS. That is correct.

Mr. GORE. Now, translated into simple English, what that means is that the Department of Energy, when it built the Paducah enrichment plant, had evidence showing that the earthquake risk to that facility was at the level of seismic zone 3, and yet it made the decision, in spite of that evidence, to use construction criteria that would be appropriate for seismic zone 1, a much lower level of earthquake risk than is actually present.

Now, have I done any—have I said anything that's unfair or inaccurate in summarizing that?

Dr. BEAVERS. No, sir.

Mr. GORE. OK. Now, the—the requirements for construction in seismic zone 1 essentially provided for no special steps for earthquake resistance because the prevailing view at that time—at the time of construction—was that the extra stress provided by wind was roughly equal to what you would need to worry about with respect to earthquakes; right?

Dr. BEAVERS. Yes.

Mr. GORE. OK. So we have a—OK; all right; go ahead with your statement. I'll come back to that.

Dr. BEAVERS. Could I expand on your comments, sir?

Mr. GORE. Yes.

Dr. BEAVERS. You made the statement that, and I have in my statement what we call seismic zone 3 requirements, but to the best of my knowledge, in 1950 when these discussions were going on, the map had just been produced.

Mr. GORE. Hm-mm.

Dr. BEAVERS. It was a new document in 1949. The design of the plants had begun before 1949, and there was some question as to the accuracy of the maps at that time.

In addition, there were no seismic design requirements in any building code, to my knowledge, in 1950.

Mr. GORE. OK; fine. And, in fact, we now know that the earthquake risk is even greater than was assumed at that time and that the requirements for construction should be much more than the ones that were in those documents in 1950.

Dr. BEAVERS. I would like to comment to the——

Mr. GORE. Sure.

Dr. BEAVERS. The Paducah area is still in seismic zone 3 for the Uniform Building Code.

Mr. GORE. OK; all right; but—all right. All right; that's fine. Go ahead. But the—but the facility is still constructed as if it was in seismic zone 1.

Dr. BEAVERS. That's correct.

Mr. GORE. OK.

Dr. BEAVERS. It's like Oak Ridge and the other plant at Portsmouth.

Mr. GORE. All right. Go ahead.

Mr. LONGENECKER. Mr. Gore, could I clarify? You've said, I believe, several times that the building was designed for the requirements of seismic code 1. What Dr. Beavers has said was that after the design was completed, it was checked against the requirements that would be imposed for that seismic zone.

As he has pointed out, there were not, when it was originally designed, those criteria, so the facility was not designed for that. After the design was completed, it was then checked against the requirements that would be imposed were you to design it again starting with seismic criteria in existence.

I'd also——

Mr. GORE. It was checked as if it was built to withstand the stresses of seismic zone 1.

Mr. LONGENECKER. Yes, sir. Just checked, rather than designed.

I'd also remind you that this plant was built for defense purposes, and there was a press at that time to support the national defense——

Mr. GORE. I'm not find—please—please understand, I'm not finding—I'm not—I'm not finding fault or laying blame with the decisions made in 1950; please understand.

We all realize there were circumstances at that time, and a mood, and a way of thinking that was different in many respects from what we have today, and although some might look back and, with hindsight, say it should have been constructed differently, that's not my purpose at all.

My purpose is to look at exactly what happened back then in order to understand what we have today and what the Department of Energy ought to take into account in making its decisions with respect to the future of the enrichment plant.

But go ahead, Dr. Beavers.

Dr. BEAVERS. In 1969, S.T. Algermissen of the U.S. Geological Survey published a seismic zone map of the United States that showed a higher seismic risk for some areas of the Eastern United States than previous understanding.

In 1970, when the International Conference of Building Officials adopted this new map into the Uniform Building Code, the concern for earthquake design and earthquake interest was increased at the Department of Energy facilities because the revisions showed

that the seismic hazard in the Oak Ridge region was greatly—was greater than previously thought.

This prompted a study by seismic consultants John Blume & Associates and Dames & Moore to investigate seismically induced acceleration effects on the gaseous diffusion building structures at all three plants. Other in-house studies looked at the gaseous diffusion plants, but as with previous studies, no process equipment was evaluated, only structures.

Recent studies associated with a \$13 million safety analysis report program for the gaseous diffusion plants looked at toxic material releases resulting from possible seismic activity. The analyses primarily focused on structural, mechanical, electrical, and instrumentation systems which were thought to impact safety if they failed, and no effort was made to evaluate the impact on total plant operations.

Earthquake levels—g levels—g being the acceleration of gravity—selected for evaluation were based on recommendations we made to the Department of Energy in the report "Recommended Seismic Hazard Levels for the Oak Ridge, TN, Paducah, KY, Fernald, OH, and Portsmouth, OH, Department of Energy Reservations."

We recommended that existing facilities be evaluated for the purpose of safety analyses using an effective peak ground acceleration value having a 10-percent probability of being exceeded during the assumed 25-year remaining lifetime of the facility.

An earthquake acceleration level having a 10-percent probability of being exceeded during the next 25 years is equivalent to an earthquake occurring having a return period of 237 years.

The respective acceleration levels are 0.18 g's for the Paducah gaseous diffusion plant, 0.08 g's for the Oak Ridge gaseous diffusion plant, and 0.05 g's for the Portsmouth gaseous diffusion plant.

This SAR seismic analysis showed that certain process piping expansion joints used at all plants were susceptible to failure due to seismically induced ground accelerations as low as 0.05 g's.

Mr. GORE. Again, with the indulgence of my colleagues, if I could interrupt you briefly there, those numbers—0.18 g, 0.08 g, and 0.05 g—those numbers measure the risk of a serious earthquake occurring at the three facilities; is that correct?

Dr. BEAVERS. That's correct.

Mr. GORE. And the risk of a serious earthquake occurring at Paducah is more than twice as great as for either of the other two facilities; is that correct?

Dr. BEAVERS. That's correct.

Mr. GORE. All right. Go ahead.

Dr. BEAVERS. This SAR seismic analysis showed that certain process piping—I'm sorry, I've already read that. Let me go on to the next paragraph.

While all the cascades containing these expansion joints—contain these expansion joints, the primary concern is with those located in portions of the plants being operated at above atmospheric pressure, a situation that only occurs at high power loads.

Such a breach of these expansion joints—should a breach of these expansion joints occur under high-power operating condi-

tions, a substantial release of process gas—UF₆—could occur, resulting in a health and safety concern.

On the other hand, if the plants are operated at power levels commensurate with subatmospheric pressures, any breach of the expansion joints would result in the inleakage of air rather than the immediate discharge of process gas, therefore minimizing the health and safety impact.

Presently, the diffusion plants are being operated at approximately 35 percent of capacity under low power and subatmospheric operating pressures.

To mitigate the effects of seismic excitations at the gaseous diffusion plants, possible approaches have been identified which include testing and modifying the susceptible components to withstand increased acceleration effects and installing a monitoring system to trip process power in the event of earthquake activity.

Modern strong motion seismic instrumentation has been installed at the diffusion plants. Also, it should be noted that seismic activity, although small, has not resulted in any operational or safety problems with the gaseous diffusion plants since they were built.

In view of the above, and based on our in-house studies and the fact that new facilities are generally considered as having 50-year lives, were the gaseous diffusion plants to be built today, they would be designed with specific seismic criteria. The likely criteria would be a 500-year return period earthquake for which the acceleration levels for Portsmouth, Oak Ridge, and Paducah would be 0.08 g's, 0.12 g's, and 0.25 g's, respectively.

Before these criteria were developed, seismic criterion for the gas centrifuge plant at Portsmouth, OH, was established at an acceleration of 0.15 g's, which corresponds to a 1,000-year return period earthquake. This criterion was taken as a conservative approach before our detailed seismic studies were completed, resulting in the more recent recommended acceleration levels to the Department of Energy.

Thank you.

[The prepared statement of Dr. Beavers follows:]

Testimony of
 James E. Beavers, Manager
 of Civil and Architectural Engineering
 Martin Marietta Energy Systems, Inc.
 Oak Ridge, Tennessee
 before
 The Subcommittee on Investigations and Oversight
 and
 The Subcommittee on Science, Research and Technology
 Committee on Science and Technology
 United States House of Representatives
 September 12, 1984

The DOE's uranium enrichment facilities were designed and constructed in the early 1950's in accordance with specific design criteria. Although, to the best of my knowledge, no seismic design considerations were given to the Oak Ridge and Portsmouth GDP's, some consideration was given to the Paducah GDP. Existing documents reveal that in 1950 discussions occurred whether to design the Paducah GDP for seismic zone 3 requirements. The Paducah area had been included in the seismic zone 3 that surrounded the New Madrid region in the publication of a seismic probability map of the United States by the U. S. Coast and Geodetic Survey in 1949. In 1952 the Pacific Coast Building Officials adopted this map into the Uniform Building Code (UBC) - a map which the U. S. Coast and Geodetic Survey withdrew that same year. After considering the necessity for designing the Paducah plant for seismic zone 3 requirements, the documents show that the decision was made to check the facilities' resistance for seismic zone 1. It was concluded that forces attributed to other dynamic and static loadings apparently were the controlling factors in the design. The prevailing view in the eastern U. S. was that wind load criteria generally provided a large degree of seismic resistance for building structures in seismic zone 1.

In 1969, S. T. Algermissen of the U.S. Geological Survey published a seismic zone map of the U.S. that showed a higher seismic risk for some

areas of the eastern U.S. than previous understanding. In 1970, when the International Conference of Building Officials adopted this new map into the UBC, the concern for earthquake design and earthquake interest was increased at the DOE facilities because the revisions showed that the seismic hazard in the Oak Ridge region was greater than previously thought. This prompted a study by seismic consultants John Blume and Associates, and Dames and Moore to investigate seismically induced acceleration effects on the GDP building structures. Other in-house studies looked at the GDPs, but as with previous studies, no process equipment was evaluated, only structures.

Recent studies associated with a \$13-million Safety Analysis Report (SAR) program for the GDPs looked at toxic material releases resulting from possible seismic activity. The analyses primarily focused on structural, mechanical, electrical, and instrumentation systems which were thought to impact safety if they failed, and no effort was made to evaluate the impact on total plant operations. Earthquake levels (g-levels) selected for evaluation were based on recommendations we made to the DOE in the report "Recommended Seismic Hazard Levels for the Oak Ridge, Tennessee; Paducah, Kentucky; Fernald, Ohio; and Portsmouth, Ohio, Department of Energy Reservations." We recommended that existing facilities be evaluated for the purpose of safety analyses using an effective peak ground acceleration (ERGA) value having a 10 percent probability of being exceeded during the assumed 25-year remaining lifetime of the facility. (An earthquake acceleration having a 10 percent probability of being exceeded during the next 25 years is equivalent to an earthquake occur-

ring having a return period of 237 years.) The respective EPGA levels are 0.18 g for the Paducah GDP, 0.08 g for the Oak Ridge GDP, and 0.05 g for the Portsmouth GDP. This SAR seismic analysis showed that certain process piping expansion joints used at all plants were susceptible to failure due to seismically induced ground accelerations as low as 0.05 g. While all the cascades contain these expansion joints, the primary concern is with those located in portions of the plants being operated at above atmospheric pressure, a situation occurring only at high-power loads. Should a breach of these expansion joints occur under such high-power conditions, a substantial release of process gas (UF_6) could occur, resulting in a health and safety concern. On the other hand, if the plants are operated at power levels commensurate with subatmospheric pressures, any breach of the expansion joints would result in the inleakage of air rather than the immediate discharge of process gas, therefore minimizing the health and safety impact. Presently, the diffusion plants are being operated at approximately 35% of capacity, under low power and subatmospheric operating pressures.

To mitigate the effects of seismic excitations at the GDP's, possible approaches have been identified which include testing and modifying the susceptible components to withstand increased acceleration effects and installing a monitoring system to trip process power in the event of earthquake activity. Modern strong motion seismic instrumentation has been installed at the diffusion plants. Also, it should be noted that seismic activity, although small, has not resulted in any operational or safety problems with the GDPs since they were built.

In view of the above, based on the in-house studies, and the fact that new facilities are generally considered as having 50-year lives, were the GDPs to be built today they would be designed with specific seismic criteria. The likely criteria would be a 500-year return period earthquake for which the EPGA levels for Portsmouth, Oak Ridge, and Paducah would be 0.08 g, 0.12 g, and 0.25 g, respectively. Before these criteria were developed, seismic criterion for the Gas Centrifuge Enrichment Plant at Portsmouth was established at an EPGA of 0.15 g, which corresponds to a 1000-year return period earthquake. This criterion was taken as a conservative approach before our detailed seismic studies were completed resulting in the more recent recommended EPGA levels to the DOE.

Thank you.

Mr. GORE. OK. Thank you very much.

Now this is a very impressive statement, and you've worked in this area for quite some time; is that correct?

Dr. BEAVERS. That's correct.

Mr. GORE. I asked some questions earlier, but I want to underscore the two points that jump out at me as a result of this statement.

No. 1, when the facility at Paducah was constructed, the Department of Energy had information that it should be classified as a seismic zone 3 area, but the decision was made, partly because of the urgency of the weapons enrichment program—the decision was made to check for earthquake risks associated only with seismic zone 1.

As a result, the facility at Paducah is—was not and is not constructed with earthquake risks in mind. It is not built to resist earthquakes; correct?

Dr. BEAVERS. None of the gaseous diffusion plants were built to withstand the earthquake levels that we are recommending based on today's state of knowledge.

Mr. GORE. OK. But Oak Ridge and Portsmouth, unlike Paducah, were built at a time when—they were built with DOE having no reason at that time to see an earthquake hazard, but Paducah, because it's on the New Madrid—in the New Madrid Fault area, even back in 1950 it was clear, even that long ago, that earthquakes should be taken into account, but they were not.

Now, later information shows that the risk of a serious earthquake of the kind that can seriously damage an enrichment facility and cause risks associated with such damage is twice as great—more than twice as great at the Paducah facility than for either Oak Ridge or Portsmouth.

Now the figures I asked you about earlier in that regard were 0.018 g. What does "g" stand for?

Dr. BEAVERS. Ground—acceleration of gravity; 32.2 feet per second.

Mr. GORE. The figures I asked you about earlier were 0.18, 0.08, and 0.05. They have been revised to 0.0—0.25, 0.12, and 0.08, respectively; correct?

Dr. BEAVERS. That's correct. I would like to clarify, though, my statement earlier that with respect to risk, these g levels are more on the hazard at the plants, not the risk. The risk has to take in all of the consequences involved with what happens when the earthquake occurs.

Mr. GORE. OK. So the hazard is more than twice as great at Paducah.

Dr. BEAVERS. Yes.

Mr. GORE. Now, what about—how do we measure the likelihood of a serious quake taking place at the three locations?

Dr. BEAVERS. We look at the historical data; that's one way; there's a number of other ways. You have microseismic instrumentation, you record the activity that's occurring today and make estimates on what the future might look like.

Mr. GORE. Hm-mm. Now, there are earthquake faults of all kinds. There is, of course, the fault out in California; there's the Fernald—well, there is a fault near Portsmouth, there's a fault near Oak Ridge, there's a rather large fault near Charleston, but the New Madrid fault is the one that has produced the largest earthquakes in North America; isn't that correct?

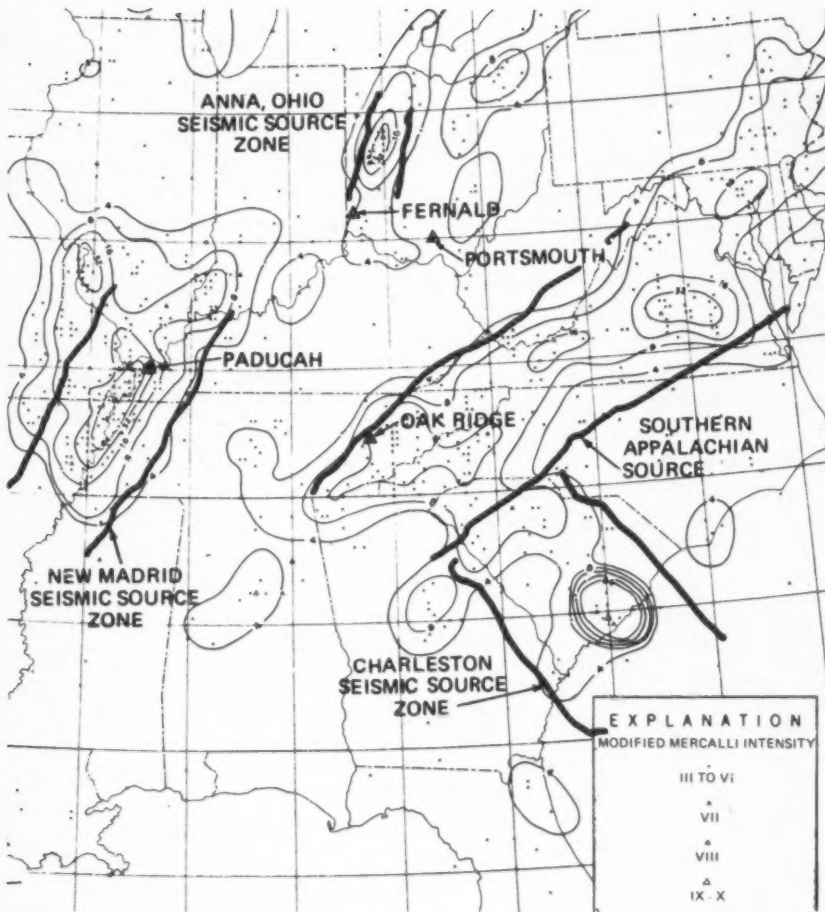
Dr. BEAVERS. That is our understanding.

Mr. GORE. In our previous hearing, we heard one statistic that the three earthquakes associated with the creation of Reelfoot Lake back in the 1800's—that those three earthquakes—1811 and 1812, from December 1811 through March 1812, if memory serves—that those three earthquakes released more seismic energy at the New Madrid fault than all of the other earthquakes in the contiguous United States combined from recorded history forward. Are you familiar with those figures?

Dr. BEAVERS. I'm familiar with those figures, yes.

Mr. GORE. I'm looking here at a map called "Earthquake Epicenters in the Eastern United States," which I would like to include in the record, without objection, which indicates that the earthquake activity along the New Madrid fault line appears to be far greater than the earthquake activity in other parts of the eastern United States.

[The map follows:]



EARTHQUAKE EPICENTERS IN EASTERN U. S.

FIGURE 3

Mr. GORE. Is that a fair conclusion to jump to from just looking at how many earthquakes have taken place in different areas?

Dr. BEAVERS. Not exactly. You have to qualify it. Since the plants have been in existence in the last 10 years, we have had strong motion instruments out. We have had more earthquake activity in the Oak Ridge-Portsmouth areas than we have in the Paducah areas, that have had any implications with respect to the plants.

Mr. GORE. Now there you're talking about tremors and small quakes and—

Dr. BEAVERS. That we have felt.

Mr. GORE. And—

Dr. BEAVERS. That have set off our strong motion instruments at the Oak Ridge plant.

Mr. GORE. Well, let's talk about large quakes of the kind that can do serious damage then. Isn't it fair to say that activity of that kind is more common along the New Madrid fault than in other areas of the United States—of the Eastern United States?

Dr. BEAVERS. The historical record shows that, yes.

Mr. GORE. OK. I'll come back for other questions.

Mr. McCandless.

Mr. McCANDLESS. Thank you, Mr. Chairman.

Having joined you a little late, I apologize. And being from California, and living about 1½ miles from the San Andreas Fault as it passes through the Chowchilla Valley, earthquakes are just a regular routine with me.

My concern here is—if I understand the thrust of the intent of our hearings, is to establish whether or not these enrichment facilities have a reasonable earthquake engineering capability built into them.

What, in the case of the ones that the chairman has been talking about, is the capability with respect to a comparison on the Richter scale, if we can make that kind of a comparison?

Dr. BEAVERS. We really can't make that kind of a comparison, because it depends on where the earthquake occurs, how far it is away from the plant, what the soil geologic conditions are at the particular site. So it's very difficult to say that the plants can withstand a magnitude 6 or magnitude 7. It's too—it's really technical and would vary based on a number of conditions.

Mr. McCANDLESS. All right. Given a certain location, the fact that you are designing this plant, that there is fault activity in the general area that could be of effect to the facility, what do you do there that you wouldn't do somewhere else in order to, say, hedge your engineering bet on the ultimate construction configuration?

Dr. BEAVERS. You—you would do things such as Dr. Hall discussed this morning—increase your bracing, add shear walls—to make the structure and its equipment more resistant.

If—my personal opinion is, if a magnitude 6 earthquake occurred at the nearest proximity to the Paducah plant at New Madrid, you—the plant would withstand that event, magnitude 6, which is what Arch Johnson had stated having a 60 percent probability—you would withstand that plant—that earthquake without any difficulties, even though our analyses show that there might be some damage.

But these structures are very forgiving, and they have a lot more—our experience, and I think some of the other people who testified today, would show that in many cases they have a lot more resilience than what we give these structures credit for.

If a New Madrid event were to occur today, we would have trouble at all three plants.

Mr. GORE. Would the gentleman yield?

Mr. McCANDLESS. Yes.

Mr. GORE. Earlier testimony indicated that the stresses already built up at the New Madrid Fault now equal 7.6. You said that the Paducah facility, in your judgment, might weather a 6 earthquake with some damage but would get through it.

What about a 7.6 earthquake? What would your opinion be on its ability to withstand that?

Dr. BEAVERS. We would probably experience expansion joint failures if it occurred nearest to the Paducah plant, but that area is an area about 150 miles long by 60 miles wide. If that earthquake occurred in some other area of the New Madrid Fault, the Paducah plant would come through without any trouble, in my opinion.

Mr. GORE. If my colleague will continue to yield just briefly, if it occurred—if it occurred within the area where the previous large quakes occurred at the New Madrid Fault, which is pretty close to Paducah, then is it your testimony that it would get through a 7.6-scale earthquake?

Dr. BEAVERS. No. If it occurred where the earthquake of January–February 1812, occurred, which is, I believe, the closest proximity, to my recollection, you would probably have some expansion joints—

Mr. GORE. Now, expansion joint failure would translate into—into what?—major structural damage?

Dr. BEAVERS. You would have moderate structural damage.

Mr. LONGENECKER. Mr. Gore, if I could perhaps clarify the answer, this is a system that is pumping large volumes of uranium hexafluoride around through 24-inch pipes essentially.

Under the operating mode that it's currently in, Paducah, we're at probably—we are at approximately 25 percent of the full power at that plant right now, and at Oak Ridge about 35 percent, and at Portsmouth about 55 percent.

Anything below about 65 or 70 percent of full capacity for a gaseous diffusion plant, you are operating in a mode such that if you were to rupture the main piping, you would actually draw air into the system rather than exhaust uranium hexafluoride.

A good example of that is in a department store where they have the little transfer tubes, you know, for transmitting messages in the little—inside tubes, if you will.

Mr. GORE. Hm-mm.

Mr. LONGENECKER. As you know, when you open that door, it ingests air into it and then draws the tube. It's the same type of thing we'd expect here.

We would not expect, under that circumstance where you had an expansion joint failure—and, again, if I could give you a simple example, it's a joint that is meant to expand and contract this way [indicating] thermally, and what you're doing in a seismic event is sheering it this way [indicating vertical movement].

You would exceed it's travel; you will tear that element to some degree, create some size hole, and under 65 to 70 percent load, you will ingest air. We would operationally note that we were ingesting air, and we'd shut the plant down.

So from a public health and safety point of view, radiological release point of view, the risk is very small.

Operationally, the question then as to repair time and getting that plant back on line is a question, but I would remind you also that these plants are made of many individual cells, and the first thing that we would do is isolate that cell of the plant, and then not all portions of the plant would be expected to react similarly, and you would not expect, in an event like that, that you would get all of those pipes deforming in the same way and failures in each area.

Mr. GORE. OK.

Mr. LONGENECKER. Is that—

Mr. GORE. I appreciate my colleague's courtesy. I took more time than I had intended to.

Mr. McCANDLESS. Just a couple of other short questions.

It's been my experience that earthquakes take different types of actions—the shearing action, the rolling action. Now maybe this fault in Kentucky, which I'm not familiar with, has a history of shearing, for example, but we have had damage from the rolling action of earthquakes that has equaled the shearing action.

Have you been able to establish when and if there is such a tremor in this fault the type of actual ground movement that will take place?

Mr. BEAVERS. Yes. We would have basically three types of ground movement—the compressive forces, then this shearing action that you talked about; we would not have any rupturing of the surface of the Earth at the ground level, not likely as far as a fault rupture like you would think in California, which occurs because of the overburden, but you would have some—the rolling action, too—the rolling wave.

The Paducah plant—we would be more concerned at Paducah with respect to the shear wave. At Oak Ridge and Portsmouth for that earthquake, we would be more concerned about the rolling wave.

Mr. McCANDLESS. There is a recent technology that I have come in contact with dealing with high-rise and large structures that are subjected, or would be theoretically subjected to such an activity, and the fact that their—their basic foundation is built on teflon pads, and that the whole structure moves, maintains its integrity, and the teflon gives it the ability to move within the Earth a 65/60-story building, we'll say, and the Los Angeles area, I understand now, will have that kind of construction.

Is that a practical application to such as the plants we're talking about?

Dr. BEAVERS. I am not an expert in that type of technology. I'm aware of it—aware of what's being done. I am not aware of any plants in the country that's using that type of technology—in this country.

Mr. McCANDLESS. Thank you.

Thank you, Mr. Chairman.

Mr. GORE. Thank you.

Now, Dr. Beavers, let me ask you about—some more questions about this question of seismic probability.

A 1973 report entitled "Seismic Design for Gaseous Diffusion Plants: Oak Ridge, Paducah, and Portsmouth, OH" outlines the probability of earthquakes in each region. Are you familiar with that report by Dames and Moore?

[The material referred to follows:]

REPORT
SEISMIC DESIGN CRITERIA
GASEOUS-DIFFUSION PLANTS
OAK RIDGE, TENNESSEE, PADUCAH, KENTUCKY
AND PORTSMOUTH, OHIO

Prepared Under
Subcontract No. 3782
Union Carbide Corporation
Nuclear Division
Oak Ridge, Tennessee

for

United States Atomic Energy Commission
Contract No. W-7405-ENG-26

April 1973

-18-

TABLE 4ESTIMATED RETURN PERIODS

Maximum Acceleration Percent g	<u>RETURN PERIOD IN YEARS</u>		
	<u>Paducah</u>	<u>Oak Ridge</u>	<u>Portsmouth</u>
5	20	60	300
10	150	550	4000
15	500	2500	20,000
20	1500	8000	--
25	3000	--	--
30	7000	--	--

DAMES & MOORE

TABLE 5

DESIGN LEVEL EARTHQUAKE ACCELERATIONS

Site	Acceleration*	Lower Level Distance**	Design Magnitude	Acceleration*	Upper Level Distance**	Maximum Magnitude
Paducah, Kentucky	10	70	7.5	30	20	7.5
Oak Ridge, Tennessee	6	70	6.5	15	20	6.5
Portsmouth, Ohio***	4	70	5.5	10	25	5.5

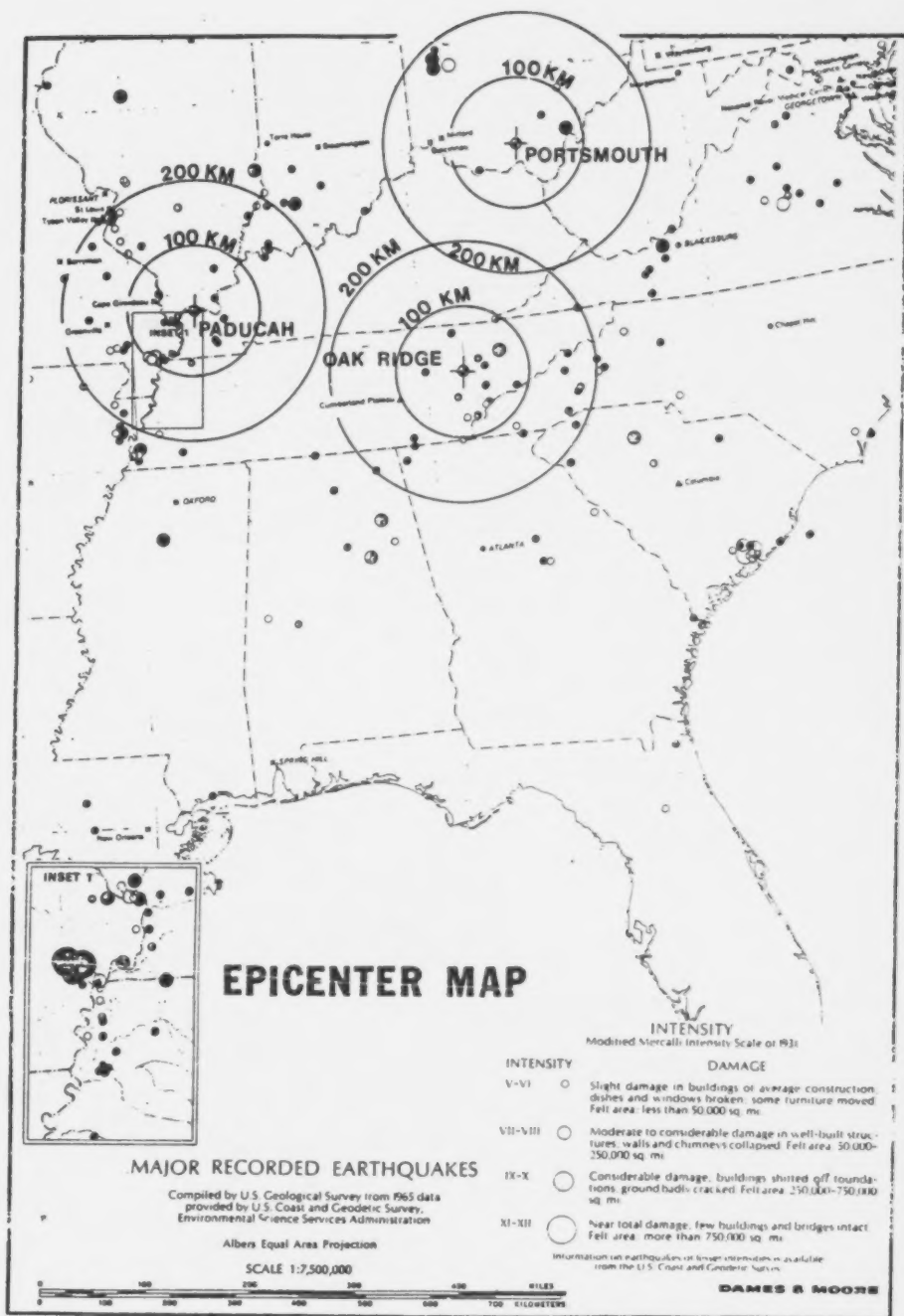
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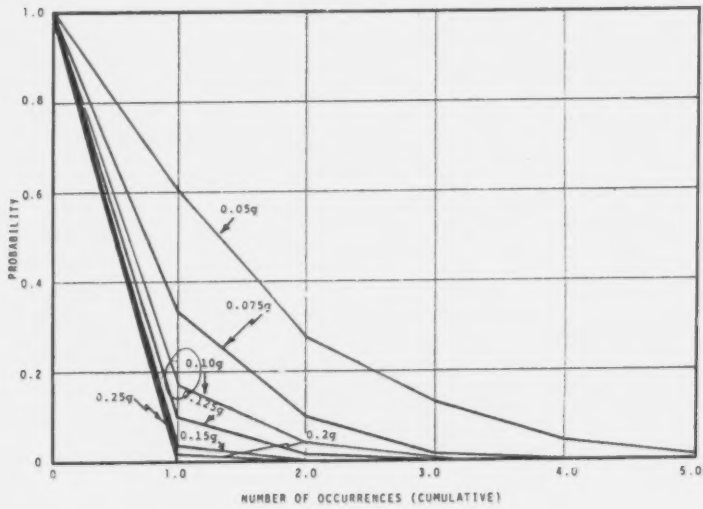
* Acceleration in percent g

** Distance to energy center in kilometers

*** Listed values for Portsmouth represent generally accepted minimum seismic motion levels and are in excess of values obtained for the risk study.

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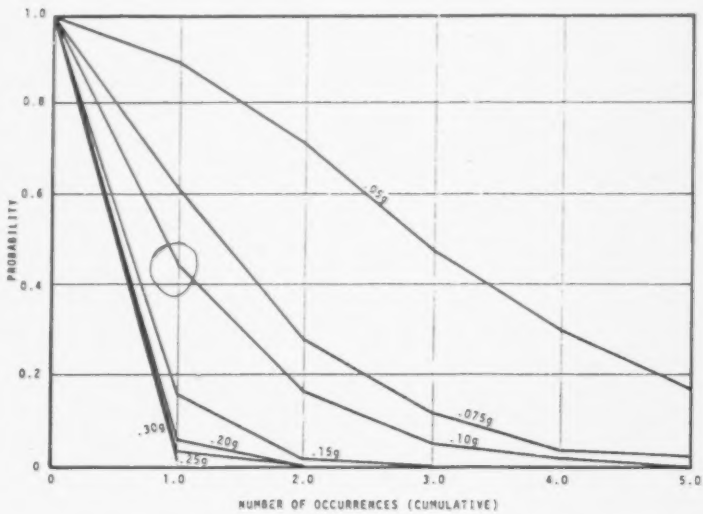
ESTIMATED PROBABILITIES

OAK RIDGE

ASSUMED PROJECT LIFE 50 YEARS

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DATE 2



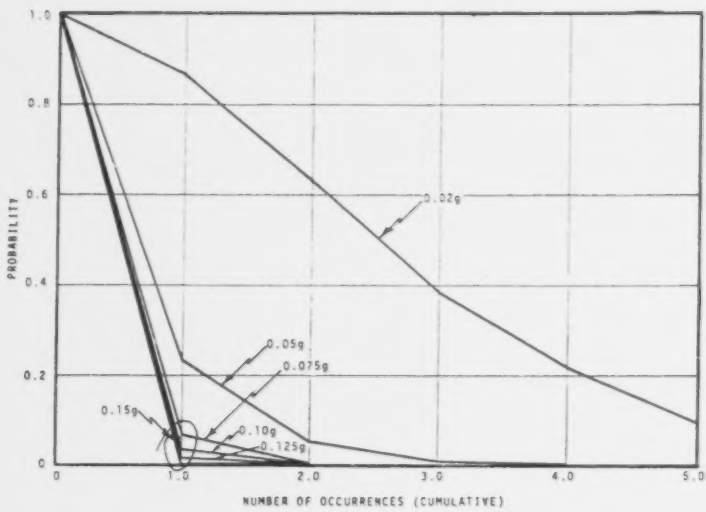
ESTIMATED PROBABILITIES

PADUCAH

ASSUMED PROJECT LIFE 50 YEARS

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PLATE 7



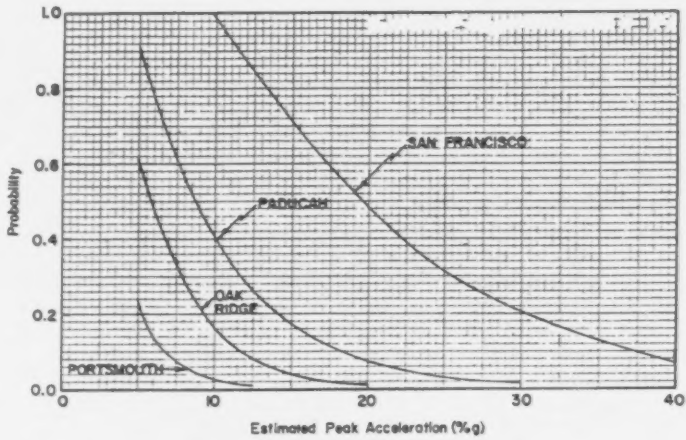
ESTIMATED PROBABILITIES

PORTSMOUTH

ASSUMED PROJECT LIFE 50 YEARS

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PLATE 8



ESTIMATED PROJECT LIFE = 50 YEARS
 PROBABILITY OF ONE OR MORE OCCURRENCE
 (Assumed Bayesian Model - $\sigma = 0.5$)

PROBABILITY OF PEAK ACCELERATION LEVELS

DAMES & MOORE

DATE 6

Dr. BEAVERS. Yes, I am.

Mr. GORE. Now, they calculated the probability of a 1-g earthquake within 50 years at each of the three sites. At Paducah, they said the probability was 45 percent. At Oak Ridge, they said the probability was 18 percent. At Portsmouth, they said the probability was 8 percent. Are these probabilities still accurate today?

Dr. BEAVERS. Generally speaking, they are in the ballpark.

Mr. GORE. OK. So my earlier statement was correct, that the risk at Paducah is more than twice as high as the risk at either of the other sites—indeed, a good bit more than twice as high.

Dr. BEAVERS. The hazard, sir, is twice as high. The—

Mr. GORE. Well, hazard, risk.

Dr. BEAVERS. The—going back to what Dr. Hall had stated in his testimony, the hazard is the earthquake levels that you might experience. The risks are the consequences if those levels occur.

Mr. GORE. OK. Well, the probability of this particular level of earthquake occurring is more than twice as high in Paducah as in either—as at either of the other facilities; correct?

Dr. BEAVERS. Twice as high—the hazard is twice as high.

Mr. GORE. No; the probability of it occurring. According to this 1973 report, the probability of such an earthquake occurring within 50 years is 45 percent at Paducah, 18 percent at Oak Ridge, and 8 percent at Portsmouth.

Dr. BEAVERS. Those are correct.

Mr. GORE. All right.

Dr. BEAVERS. Generally speaking.

Mr. GORE. OK. Now the earlier figures I used related to the hazard, and there that was the g number—

Dr. BEAVERS. Hm-mm.

Mr. GORE. Point 18 for Paducah; 0.08 for Oak Ridge, and 0.05 for Portsmouth. So both the probability of the event and the hazard of the event are twice as great—more than twice as great in Paducah as with the other two—as with either of the other two plants.

Dr. BEAVERS. The probability of events of the g levels that are shown there is the same for all three plants.

Mr. GORE. Well, now, it says here—it says here in the 1973 report—and you said you believed these figures to be accurate, and I'm not a scientist, so I want you to help me understand this, but this 1973 report says that the probability of an earthquake—and they give the specific level—within 50 years is 45-percent probability in Paducah, 18 percent probability in Oak Ridge, and 8 percent probability at Portsmouth.

Now that—the way I read that—and you tell me if I'm wrong—that seems to say that there is a 45-percent probability of that specific level of earthquake occurring; OK? Doesn't it?

Dr. BEAVERS. That's the—that is the probability of a level of earthquake causing a certain g level at each plant. It's 0.1 g's at each of the three plants.

Mr. GORE. OK. That's—

Dr. BEAVERS. That's the probability that you would have the same earthquake level at each plant. The other numbers are assuming you have a given probability number, and you end up with varying levels of earthquake accelerations.

Mr. LONGENECKER. Mr. Gore, put another way, the probabilities in the one study do not go with the seismic accelerations in the other.

Mr. GORE. I'm not—I'm not trying to marry them together. I just think—I'm just saying that in both cases the probability and the hazard are both twice as high at Portsmouth—as—I mean at Paducah than at the other two plants.

Now—

Dr. BEAVERS. In one case you're holding the accelerations constant; in the other case, you're holding the probability constant. So you—you don't—

Mr. GORE. OK. All right. Now, that's absolutely correct; that's absolutely correct.

In the 1973 report, they're holding the acceleration constant; right?

Dr. BEAVERS. Right.

Mr. GORE. And they're measuring how likely will an earthquake of a given—how likely is it that an earthquake with a given acceleration will occur at each of the plants; right?

Dr. BEAVERS. Correct.

Mr. GORE. OK. And they're saying it's more than twice as likely—

Dr. BEAVERS. Right.

Mr. GORE [continuing]. That such an earthquake will occur at Paducah than at either of the other two plants; OK?

Dr. BEAVERS. Yes.

Mr. GORE. All right.

Now in the other—in the other study, they're saying, OK, let's assume that an earthquake takes place at each of these three plants. Then, how likely is it that—or how high will the g level likely reach at each of these three facilities. You're holding—you're holding the probability constant there, you're assuming that one takes place, and then you're measuring how much acceleration will occur; right?

Dr. BEAVERS. That's—yes.

Mr. GORE. And there, the hazard, as measured by the acceleration, is more than twice as great at Paducah than at either of the other two plants; right?

Dr. BEAVERS. Which says the overall hazard is—is about twice at Paducah than the other two plants. You don't—

Mr. GORE. OK. Both the probability of the event occurring and the—the level of hazard presented should an event occur is more than twice as great at Paducah than at either of the other two plants.

Dr. BEAVERS. That's—that's the way it should come out.

Mr. GORE. OK; all right; OK. That's—that's all I'm trying to establish.

Now, Mr. Longenecker, having established that fact—those two facts, and having established the fact that the construction at Paducah was undertaken without regard to the best evidence available at the time of construction, I'm sure you have looked at the cost of retrofitting these facilities in accord with the varying levels of risk presented at each, and I have seen studies at the Department of Energy which indicate—I believe I've—has a decision been

made at the Department of Energy, Mr. Longenecker, that retrofitting—I'll wait till you get through there.

Mr. LONGENECKER. I'm sorry.

Mr. GORE. That's all right.

Has a decision been made that retrofitting is not cost-effective for these facilities to bring them up to the earthquake resistance levels that the evidence indicates is appropriate?

Mr. LONGENECKER. I can't answer that question because of the way you've posed it.

The evidence indicates it's appropriate. I'm not sure that our definition of what would be appropriate retrofit would—would match, but let me try and answer within the confines of how we view the problem.

There are two manners—two basic types of retrofit that one might look at, Mr. Gore. The first is one that would say, If I wanted to design these plants, or retrofit them, so that at full power, or at greater than 75 percent power, in the event of an earthquake, that would give me an excitation of 0.05 or 0.1 g—on that order—what type of retrofit would I require to get that kind of protection? We have looked at that. It is basically one of strengthening the weakest link in that event, and it is the expansion joints.

Mr. GORE. Yes.

Mr. LONGENECKER. To give you an example, there are over 100 of those that we would strengthen at Paducah, fewer than that at the other 2 plants—probably 80 or 90—and at Paducah, that's estimated to cost \$1.5 to \$2 million to make that type of retrofit.

The other type of retrofit that I believe you may have been alluding to is one that says, "If I went back and retrofitted the entire plant to do everything the way I would do it to today's standards." We have not looked at that.

My intuition tells me that that type of retrofit is—is not in this case, and is generally not for industrial facilities, cost effective.

Mr. GORE. OK. Well, now, wait a second. Your first response merely assumed that you would take the weakest link, and yet there was a 1981 report that was entitled "Seismic Evaluations of Process Buildings at Gaseous Diffusion Plant" that looked at the major weak links at the Paducah facility, and they found several major weak links, and you—you only mentioned one of them, the expansion joints and piping, which would receive damage at 0.01 g, according to this report.

The second is flexible structures, such as unit process buildings, tie-line support structures, et cetera, which would receive damage at 0.05 g; one-half of the level that is 45 percent probable.

No. 3, unrestrained equipment, such as piping systems, again, would receive damage at 0.05 g; and, No. 4, unreinforced block walls, such as in control room in C331, major damage at 0.05 g.

So, in answering the question about retrofitting, I don't think it's appropriate to just take one of the—of the four major weak links found in this 1981 study at Paducah.

Mr. LONGENECKER. Well, the answer is that it depends on what you're trying to fix.

Mr. GORE. Yes.

Mr. LONGENECKER. From a public health and safety standpoint, you would replace the expansion joints.

When you look at the plants and you say, first, what's your definition of "damage," from an engineering point of view, as soon as you get plastic deformation, not rupture or failure of that system, you have sustained some damage.

Bending of beams is damage. That may not incapacitate the plant. It certainly wouldn't result, in most cases, in radioactive release, but that is damage in the strictest sense of the word.

So, we've looked at it from the point of view of, if a block wall falls down in the control room, does it incapacitate the plant or threaten health and safety, and the answer is that it does not.

So the answer—

Mr. GORE. It may be very expensive to get it fixed, so that the thing can operate.

Mr. LONGENECKER. That's right; that's right; and that's the point that I was raising, Mr. Gore. We separate the two, and one is public health and safety consequence, on the one extreme, making sure that the plants are safe to operate during the rest of their expected life, and, on the other extreme, trying to do all the things that, from an engineering point of view, if you went in and said, knowing what I know today and the progress that's been made in the last 30 years, if I wanted to go back and redesign that plant, what could I do? And that's the difference between the two. You would make some things stronger than you did in 1950.

Mr. GORE. OK. Well, we've got—

Mr. LONGENECKER. Could I add another point on the perspective of the plants? Mr. Gore, you mentioned the probabilities of events and the periods of time. Recall that these plants' expected operating life is—although they could operate past the turn of the century, it's unlikely, due to their economics, that they will. So that's another factor that we use.

Mr. GORE. In—in retrofit decisions.

Mr. LONGENECKER. In retrofit and in operation decisions, as to how long will the plant operate, and then, within that period, what's the probability; and, again, even more importantly, during the period of its life, at what power level do we believe it will be operating?

All of those are unknowns at this time, and as I said in my overview remarks, we need to factor those in, but the key thing that we don't know today in trying to develop a production plan, before you just make any decision on seismic retrofit is, one, what the total demand is that we will see, civilian and military, for the next 10 years. We will know that in the next few months, from the conversion to the U.S. contract.

Mr. GORE. OK. We've got other witnesses. Let me summarize what I think I've heard from the two of you and what I think the implications are.

First of all, the seismic risk at one of these three plants, Paducah, is twice as great as the seismic risk at either of the other two plants.

Second, the probability of a given seismic event at one of these two plants, Paducah, is more than twice as great as at either of the other two plants.

Third, the cost of full retrofit may be quite extensive.

Fourth, the construction at Paducah originally proceeded, in spite of evidence available at the time that would have called for seismic precautions at a minimum testing far greater than was performed.

Now, the conclusion I draw from all that is very simple. As the Department of Energy studies its difficult decision about which of these facilities may not be allowed to continue operating in the future, it is imperative that the Department of Energy give full and complete consideration to the extra and excessive earthquake risk at Paducah, as compared to the other two plants that are under consideration.

Now, I know that the decision will involve many other factors, but I want to make certain that the Department of Energy takes fully into account this factor that we've been discussing this morning.

Mr. LONGENECKER. Mr. Gore, I guarantee you we will. I would reiterate that we will evaluate that factor, however, and its relative importance—seismic vulnerability now—due to a low-probability event in the limited remaining life of the GDP's against other factors, including the economics of operation and the others.

So, there are a number of factors we will fully consider. It is only one of the factors as, say, from our perspective, we also recognize that it is a reasonably low-probability event in the remaining operating life.

Mr. GORE. What do you estimate to be the remaining operating life?

Mr. LONGENECKER. It varies for each of the facilities. I, personally, would be surprised if, in 20 years, you have any of the three operating.

Mr. GORE. Well—

Mr. LONGENECKER. That's not a result—

Mr. GORE. When you say—when you say low probability, we have had testimony in our previous hearing which indicates that the probability may not be low at all, depending upon the level of acceleration that one would expect to accompany—

Mr. LONGENECKER. Compared to other events, I'm saying I know what it costs to operate each three plants with 100 percent probability tomorrow, and, then, weighed against that is their other natural phenomena which have some probability lower than 100 percent.

Mr. GORE. Well, now, let's talk about low probability; OK? You used the figure, 20 years. Let's use the figure of 16 years. That's how much time is left in this century.

We had testimony from one of the leading earthquake experts in the country at our previous hearing which estimated that in the New Madrid fault area, there is a 63-percent probability of a 6.3-magnitude earthquake before the year 2000.

Would you say that 63 percent is a low probability?

Mr. LONGENECKER. I can't make a judgment on low versus high. My—

Mr. GORE. Well, I mean, you know, all that's required is arithmetic for that. I mean 63 percent is not a low probability, is it?

Mr. LONGENECKER. It's lower than the probability of what it will cost to operate the plants tomorrow or the relative efficiencies, which I know.

My point was only that you must weigh, first of all, the probability of that event, its consequences if you had an event of Richter magnitude 6.3, which you heard Dr. Beavers say we believe for any of the three plants is probably survivable with minimum damage, against the other factors that you know, and that is age of the plant and their relative efficiency and their cost.

So it is a lower probability event than some of the others that we know will occur.

Mr. GORE. Well, I think you're mixing probability and cost, and they're very different items. It's like mixing apples and oranges.

Mr. LONGENECKER. Not in a case——

Mr. GORE. I'll grant you——

Mr. LONGENECKER [continuing]. It certainly isn't.

Mr. GORE. I'll grant you that the probability of an earthquake with a magnitude more than 6.3 is certainly less than 63 percent, but I don't think that it's fair to say that it is a low probability event, particularly when it's unclear about the effect of a 6.3-magnitude earthquake. That's based only on Mr. Beavers' educated guess, that the facilities might withstand a 6.3 earthquake.

In fact, Mr. Beavers, there's some uncertainty about what damage might be associated with a 6.3 earthquake. Would you agree with that or not?

Dr. BEAVERS. We do not expect—we expect minor damage at the plants at a 6.3 earthquake. The minor damage is walls cracking, just small spalling of concrete, nothing significant.

There is a possibility at the 6.3, as I stated earlier, of some expansion joints problems—failures.

Mr. GORE. OK.

Dr. BEAVERS. There's a potential.

Mr. GORE. But releasing uranium hexafluoride? Not necessarily?

Dr. BEAVERS. No, it would not be released under today's conditions.

Mr. GORE. OK; all right; fine; all right; that's fine. All right.

Mr. McCANDLESS. Would the chairman yield?

Mr. GORE. I'd be glad to.

Mr. McCANDLESS. I get kind of hung up on that 63 percent probability.

Mr. GORE. Yes.

Mr. McCANDLESS. I understood the thrust of your question that there would be an earthquake, but that the magnitude of that earthquake is yet to be determined based upon when it—if and when it does arrive, and that if I understood my conversation with Mr. Beavers, the design is somewhere in the neighborhood of a 6.

So if we ended up with a 4 and that 63-percent probability, then we would have a relatively two-thirds of whatever it is that supposedly would happen at the 6 level, even though we have a logarithmic differential between 4 and 6.

I'm interested in what I think is the thrust of these hearings, and that is, of the 63-percent probability, what is the percentage of that probability that would be 6 or greater?

Mr. GORE. Well, the testimony earlier was that there was a 63 percent probability of an earthquake of magnitude 6.3 in the New Madrid area—

Mr. McCANDLESS. I didn't quite understand it that way. Maybe I misunderstood.

Mr. LONGENECKER. Mr. Gore, I believe—

Mr. GORE. No; no. That's the testimony of Dr. Arch Johnson at an earlier hearing.

Mr. LONGENECKER. I believe that's 40 to 63 percent, is it not?

Mr. GORE. Pardon me?

Mr. LONGENECKER. I believe his testimony said it was in the range of 40 to 63 percent.

Mr. GORE. Oh, excuse me; yes. I was—I was using the—your—I stand corrected. His testimony was that it is as high as 63 percent; you're quite correct; and this was—I'm using a contracted version here, and I have the study in front of me.

You're quite correct. It says the chance of a 6.3 earthquake is within a range of 40 to 63 percent. I did not intentionally leave out the 40 percent; I was working from a figure—from a sentence that says "as high as a 63-percent probability."

He also testified that the stresses currently built up in the New Madrid fault area approximately equal an earthquake of magnitude 7.6 at the present time. Of course, those stresses are not all released at the same time in every case; of course, they could be.

Dr. BEAVERS. May I elaborate, Mr. Gore?

Mr. GORE. Sure.

Dr. BEAVERS. These probability numbers that Dr. Johnson testified in previous hearings are estimates themselves.

Mr. GORE. Yes.

Dr. BEAVERS. As the 40 to 63 percent indicate, where he has been able to come up with these estimates has been based on primarily 10 years of microseismic activity. That's earthquakes of Richter magnitude 4, 3, 2, and 1, and he is making projections here out to large earthquakes that have recurrence intervals of 100, 200 years, et cetera, using this data, even 1,000 years, when he does a probability estimate on the magnitude 8.3.

So these are very rough estimates as to whether it's 40 percent, 20 percent, for a Richter magnitude 6.3; that's still debatable in the scientific community.

Mr. GORE. Yes, and I think his statement in the record of that earlier hearing, I think, is consistent with what you say.

The science has not yet progressed to the point where people can be specific about what these probabilities are. You can take a stab at it and come up with estimates, and that's what—that's what he has done; it's what others do.

Well, let me—let me thank you for your testimony, and, again, in conclusion, let me urge you to make the fullest possible use of this criterion and take it fully and completely into account in your decisions about the future of the enrichment program.

Mr. LONGENECKER. We will, Mr. Chairman. Thank you.

Mr. GORE. Thank you very much.

Now let's go to our final panel of witnesses, Dr. Thomas D. O'Rourke—thank you—Dr. Thomas D. O'Rourke, associate professor at the School of Civil and Environmental Engineering at Cor-

nell; Dr. Anshel J. Schiff, professor at the Department of Mechanical Engineering at Purdue; and Dr. Irving J. Oppenheim, associate professor at the Department of Architecture and Civil Engineering at Carnegie-Mellon University.

We're delighted to have all three of you here. We will take again a somewhat broader focus with this panel, and we will look at lifeline systems, and this is again part of our continuing examination of this entire topic. We're pleased and thankful that you could join us.

Without objection, your prepared statements will be included in the record in full. We invite you to proceed, Dr. O'Rourke.

STATEMENTS OF DR. THOMAS D. O'ROURKE, ASSOCIATE PROFESSOR, SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING, CORNELL UNIVERSITY, ITHACA, NY; ANSHEL J. SCHIFF, PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, PURDUE UNIVERSITY, STANFORD, CT; AND IRVING J. OPPENHEIM, ASSOCIATE PROFESSOR, DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING, CARNEGIE-MELLON UNIVERSITY, PITTSBURGH, PA

Dr. O'ROURKE. Thank you very much, Mr. Chairman.

With your permission, I have brought some visual aids that will help to focus our attention on some of the principal items I would like to talk about, which parallels my written testimony which has been submitted.

Mr. GORE. OK.

Dr. O'ROURKE. Thank you.

What I would like to do is confine my talk, again, as I said before, to parallel what I have submitted as written testimony and to focus in particular on three items.

[Slide.]

Dr. O'ROURKE. No. 1, what constitutes a lifeline; No. 2, to discuss just briefly what some of the earthquake risks would be in the eastern United States; No. 3, to take a look at what kind of mitigative measures can be undertaken to improve earthquake performance of lifeline systems; and, No. 4, to look at areas where there is need for future work.

[Slide.]

Dr. O'ROURKE. To begin with, a lifeline may be defined simply as a structure which provides a pathway for people, resources, and vital services, and certainly in the wake of an earthquake, it is very important that pathways exist so that people can move from one place to another, that resources can be provided to the areas which have been stricken by the earthquake, and that vital services can also be available.

In fact, lifelines—and we've had many examples of them this morning with regard to water systems, and fuel, and so forth actually are the principal means whereby we are able to enact life-saving activities, contain the area of damage, and also restore the community to its normal productive and operating conditions.

Therefore, lifelines become a very critical aspect, a central factor in any plans for emergency management during earthquakes.

[Slide.]

Dr. O'ROURKE. The ASCE Technical Council on Lifeline Earthquake Engineering identifies four major groups of lifelines. These are—and they are listed—electric power and telecommunications systems, gas and liquid fuel, transportation systems, and water and sewage systems.

I'd like to point out that the lifelines not only involve structures which provide pathways within these systems, but they also involve certain critical facilities.

So, for example, if we're talking about a water distribution system, there may be pump stations, there may be storage tanks, there may be reservoirs, which are site specific locations, which involve themselves in the distribution of that particular resource.

There are several distinctive features about lifelines which really need to be underscored and understood.

No. 1, their most distinctive feature is their large physical size. Lifeline systems encompass many square miles and are therefore subjected to many different seismic and geotechnical conditions.

The level of earthquake ground shaking will vary throughout the region that the lifelines may cover, and also the conditions of the ground—the potential for ground movement, the potential for ground failure—will vary from one location to another.

In fact, it's very important to consider these geotechnical conditions because they have important implications in terms of the response and the ability of the lifeline systems to perform.

Another distinctive feature with respect to lifelines—and also to return to this—very often it's easy for us to consider a structure which is placed locally and therefore can be a matter of focused sort of investigation and appraisal of a hazard, but with a lifeline system which covers a large area, very oftentimes there are hazards which have to be crossed and intersection which can't be avoided because of rights-of-way and need to distribute these services to various areas.

Another distinctive feature is that they are interconnected. That is, something which will happen in one part of a lifeline system, even though it is removed extensively in terms of area, may have a very dramatic impact on the ability of that system to perform in another area.

So breaking a, for example, water line close to the area of where the water is provided has a very important impact on being able to distribute it many miles away.

And finally, lifeline systems are interdependent. It's convenient at times to consider one individual system, such as a water system, but it also functions interdependently with a sewage treatment system, or it will function interdependently with a gas distribution system.

[Slide.]

Dr. O'ROURKE. This slide just illustrates the interdependency. This slide is from the 1971 San Fernando earthquake. It's located at an area where there was surface faulting, or permanent ground displacement, and there is a sewer line, a water line, and a gas distribution line shown in this photograph. Certainly the implications in terms of damage to the sewer line and possible contamination of drinking water are apparent.

This slide also shows something else in terms of the continuity, the ductility, of the gas distribution line here. We see that it's not broken or pulled apart as distinctly as the others are at their joint, even though it is deformed. So there is damage to that particular lifeline, but there is not a disruption of service or a creation of a particular risk at that area.

[Slide.]

Dr. O'ROURKE. Bridges are another example of part of transportation systems which are involved in lifelines.

This is a picture of bridge damage from the 1964 Alaska earthquake, and what I'm trying to emphasize here is that oftentimes we think of bridge structures as being the structural element which connects two banks of a river crossing, and oftentimes we don't think of the banks of the river and the embankments which lead up to that structure as being important components of that particular element of a lifeline system, and very often it's these which are particularly susceptible, and here there has been some spreading and some movement of the banks of this particular river which have had a dramatic impact on the ability of this structure to perform its services.

[Slide.]

Dr. O'ROURKE. What I have here is a picture which is fairly well known in earthquake engineering. It shows the intensities for various earthquakes which have occurred in the contiguous United States.

We can see that on the west coast there is a dark shaded area and a hatched area, and the dark shaded area is associated with intensities which are 8 or greater, and by intensities I mean the Modified Mercalli Scale, and the cross-hatched areas are areas which show intensities that vary from 6 to 7.

We can see here, by contrast, that some of the more significant earthquakes, the 1906 San Francisco and the 1971 San Fernando, are associated with relatively small area distributions relative to the 1811 and 1812 New Madrid earthquakes and the 1886 Charleston earthquake, which is shown down in the Charleston area.

This has some important implications with respect to the potential for damage following an earthquake in the Eastern United States in that, No. 1, the earthquakes have a tendency to distribute the intensity through a greater area than what we are accustomed to in the Western United States. They also are many times affecting locations which are more heavily populated, and they are also having an impact on areas which are associated with river deposits.

[Overlay slide.]

Dr. O'ROURKE. Now, what I've done on this particular overlay is to take away the shading associated with the intensities and have drawn in the river—the contours of the Missouri, the Ohio River, and the Mississippi River, and we can see that this confluence occurs very close to the center of intensity in the 1811 and 1812 New Madrid earthquakes, and these sorts of areas, where the rivers converge, are associated with alluvial deposits, alluvial plains, flood plains, of various stream channels, and so forth. These areas can be, and are likely to be in some circumstances, susceptible to what we call soil liquefaction.

[Slide.]

Dr. O'ROURKE. Soil liquefaction may be defined as the loss of soil shear strength because high water pressures have caused in the process of the earthquake ground shaking.

When this happens, in some cases the loss of inherent strength in the soil mass may be so great that it performs as if it were a liquid. In other cases, it may perform with less than its normal shear strength and still deform excessively although it doesn't quite perform as if it was a liquid material.

Soil liquefaction can have an impact on the foundations for structures in areas which are subject to earthquake activity. It also can cause large permanent types of ground displacements which can involve buried lifelines, such as pipelines for gas distribution or transmission and water distribution and transmission.

In fact, there's a form of soil liquefaction in this ground which is referred to as a lateral spread, and the lateral spread actually involves the liquefaction, or the loss of shear strength, in a soil deposit which is beneath a competent soil deposit, one which has not been subjected to liquefaction, but because the underlying deposit has been subjected to a loss in shear strength, it tends to move down whatever slope it's located on, and it pulls the competent material with it.

Now the implications for this are that if pipelines are buried in the competent material, there will be a significant deformation imposed on them because competent, strong soil is being forced to move against them.

[Slide.]

Dr. O'ROURKE. Examples of this can be seen in this particular photograph, which is from an 1886 Charleston earthquake, photograph compiled by Dutton who investigated that, and you can see this railroad line has been deformed significantly out of line at this particular location.

This also gives us an opportunity to see how we can learn from west coast earthquakes about the possible implications with respect to damage or consequences of earthquakes for the East.

[Slide.]

Dr. O'ROURKE. This, again, is a railroad line which was distorted in an area of lateral spreading during a 1971 San Fernando earthquake.

We can see that there is a very close correspondence to the two—between the two, and you can also see that the slope of the ground here is very small. In fact, lateral spreads may occur at inclinations which are as small as a half a degree.

So it's not easy to detect locations of potential lateral spreading ahead of time, but we're learning a lot more, thanks to investigations that have been advocated and sponsored by the National Science Foundation and the U.S. Geological Survey.

[Slide.]

Dr. O'ROURKE. Now the implications here—and this just shows it again sort of as a three-dimensional view—that if a pipeline structure is involved in a large mass movement of the ground, it is unlikely that we can design it to have sufficient strength and resistance to, in its own right, resist the mass movement of that ground.

By the way, the differential movements here from the center of the spread to the edges of the spread can be from 5 to 10, and in some cases as high as 20 feet.

So the implications here are that if we are trying to focus on a couple of issues of importance with regard to mitigating damage to buried structures, it is important to be able to allow them to deform with the ground and continue to maintain their own continuity. In terms of providing the service and preventing disruption, it becomes a very key item.

[Slide.]

Dr. O'ROURKE. Earthquake mitigation then involves critical structures, such as the pump station, such as the storage tanks, such as the reservoirs, where we can't—we certainly need to, and in fact in most cases we need to site them away from geotechnical hazards that may be associated with liquefaction, that may be associated with potential landslide activity.

Well, the line structures which distribute out and cover broad geographical areas, we need to be concerned about their connections with more rigid structures in the system. So flexible connections become an important concern, because that allows these line structures to move relative to a more rigid body.

Now as an example of this, many transmission pipelines for gas and for water cross bridges, and as they cross bridges, they have to cross through an abutment, which is generally some form of a concrete abutment that can be a very rigid structure.

Here is a potential for potential differential displacements at that location and the need to provide some flexibility at that connection point. Obvious other examples include connections with tanks and so forth.

Ductile performance. We know from our previous experience during earthquakes that continuous, butt-welded, electric arc pipelines of the type that are used for gas transmission systems are among the strongest structures that's really constructed by man. They have amazing strength and capacity for distortion because they perform ductally, provided that we are able to site them in cases, or in situations, where they will be—will be able to take advantage of their elongation capabilities, and I'll show an example of a case where that didn't happen.

But I know—and I've looked very closely at the record—of only one case where a modern electric arc-welded transmission line actually had a rupture, and it was at a weld. It was during the 1971 San Fernando earthquake, and from all the other earthquakes—North American earthquakes in this century, I cannot find another example.

Finally, a review of vulnerable lines. We know from previous earthquake experience that there are certain structures which are more vulnerable, and here this enters into this assessment of risk, because all structures are subjected to the hazard. Some structures have a greater risk because their capacity is lower, given a certain hazard.

Here there are certain lines. For example, we know that during the 1920's there was a type of steel that was manufactured in Europe called Mannesman and Metheson steel, and that was

brought over to the United States and used in water distribution systems.

This material, over time, has been recognized as a relatively bad actor with respect to internal corrosion, which also weakens those kinds of pipelines with respect to seismic activity, and they have performed poorly in previous earthquakes.

I'll cite another example with respect to transmission systems in a minute.

[Slide.]

Dr. O'ROURKE. To illustrate some of these, this is a pulled out connection at a water storage tank which occurred during the 1957 San Francisco earthquake, and here you can see that this particular connection was only connected in here to this joint by virtue of a cement coating. That was not a particularly flexible structure, and it certainly wasn't an extensible structure.

But yet recognizing that this particular tank was founded on piles, or deep foundations, but the connections to that tank, and therefore the tank didn't—wasn't subjected to severe distortion, but the connections to the tank were not, and so when the ground settled as a permanent displacement relative to the tank, it pulled out this important connection, and these can be important.

So in areas where we recognize that we have these kinds of connections, oftentimes it's a matter of some reasonable detailing to bring in additional flexibility and extensibility of these connections between the lifelines and the more rigid structures.

[Slide.]

Dr. O'ROURKE. This is an example of a 16-inch diameter transmission pipeline during the 1971 San Fernando earthquake which was severely compressed at a fault crossing which involved severe compressive displacement, and this illustrates what I mean by recognizing the capacity of pipelines to be able to elongate if they're constructed of modern steels, and recognizing that they need to be sited so that they can elongate.

In certain cases when they are subjected to compressive displacements, they undergo what we call a plastic wrinkling, which takes these geometric distortions and bunches them up in one location and makes them vulnerable.

So it's not only the composition of the line, but it's its orientation in siting with respect to the potential for permanent displacement.

[Slide.]

Dr. O'ROURKE. And finally, in terms of identifying potentially weak systems, we do know from previous earthquake experience that this kind of experience becomes important when we're looking at east coast scenarios of plate lines which were welded when current welding practices involve a good bevel, good what they call root penetration, so it goes right through the thickness of the pipe here, and a good toe weld with no overlapping and so forth.

We do know that certain pipelines which were constructed generally before 1932 did not benefit from the same quality assurance programs in welding that we experience today, and that's not all of them, but there is a tendency for some of them not to have the same quality of weld, and these end up weakening the pipelines, and we've seen breaks in high pressure pipelines during the 1971 San Fernando earthquake, the 1933 Long Beach, and the 1952

Kern Counties, which involve the breaking at these particular welds, and there are some pipelines in the East which were also constructed according to the same.

I'm not saying that those are particularly ones which are likely to fail, but they are points of concern which at least should be reviewed in terms of the repair record on the line in assessing the potential risks associated with earthquakes.

Now to summarize, I'd like to just make a comment with regard to where we are and what our needs are with respect to future work.

I think we've learned a lot from our experience, particularly in recent years, focusing on the 1971 San Fernando earthquake, the Coalinga earthquake, and so forth, on the west coast, and we have now a good understanding of how many components in lifeline systems perform in the systems in general, and I think that one thing we could do for the east is to encourage a greater implementation of the lessons we have learned and some of the relatively low-cost ways in which the safety and performance of the facilities can be upgraded.

I think that a second area for future work involves research with respect to geotechnical hazards, particularly those associated with soil liquefaction. There has been a great deal of good work done in the last 20 years, principally through, again, the National Science Foundation and the USGS in defining what kinds of forces, soil, and water conditions give rise to the occurrence of liquefaction.

But for buried lifelines, it's not just sufficient to know what will happen, or to know if liquefaction may occur, but, rather, what form of ground displacement will occur when and if liquefaction occurs, and here we need some interdisciplinary work among geologists, pipeline engineers, geotechnical, and so forth.

I think another area of great potential is recognizing that pipelines are systems, that they are interconnected, that they are interdependent, and applying what—certain things we've learned from systems analysis, which essentially use probability as a tool for predicting the likelihood of sectional performance and aerial performance in pipeline systems; and, with the given increase in the computer technology, the ability to be able to represent these complex systems relatively easily with the great miracle analysis capabilities that we have now, I think we have some great gains to be made here by providing models and tools for utility engineers actually to experiment with potential hazards and what the risks of those hazards are for the systems that they are dealing with.

Thank you.

[The prepared statement of Dr. O'Rourke follows:]

STATEMENT OF T.D. O'ROURKE, ASSOCIATE PROFESSOR, SCHOOL OF CIVIL AND
ENVIRONMENTAL ENGINEERING, CORNELL UNIVERSITY

1.0 INTRODUCTION

A lifeline is a structure which provides a pathway for people, resources, and vital services. Examples of lifelines include pipelines that distribute water for domestic use, industrial activities, and fire fighting. Other examples include natural gas and liquid fuel pipelines, the telephone, electric power lines, and transportation systems.

Lifeline failure involves the loss of resources and services. Most people take their water and telephone services for granted and don't think that a failure in these systems can be catastrophic. Nevertheless, the loss of these resources during an earthquake will have severe repercussions on the ability to save lives and property. The 1906 San Francisco earthquake is a good example of how lifelines are important for earthquake response and emergency services. The most severe and widespread cause of damage associated with that earthquake was from fire that spread through San Francisco because the ruptured pipeline system could not provide adequate water.

Lifelines are the principal means by which life-saving measures are undertaken, damage is contained, and normal activity and productivity is reinstated. Understanding lifeline systems is a key aspect of emergency management, and a vital component in planning for regional and local emergency response. Moreover, changes brought about by earthquake considerations contribute to the overall quality of lifeline systems and need not result in substantial cost.

This testimony summarizes considerations for lifeline earthquake engineering in the eastern United States, which includes the area east of the Rocky Mountains. A brief description of lifelines is given, and earthquake hazards in the eastern United States are discussed. Measures to improve lifeline performance during earthquakes are described, and the need and benefits associated with additional work in this field are examined.

2.0 LIFELINE SYSTEMS

The most important physical characteristic of a lifeline system is its size. Lifelines extend over large areas. They generally are parts of networks and are composed of many interconnecting segments. In some cases, a lifeline system may consist of a single long structure which traverses a great distance. High pressure natural gas and liquid fuel transmission lines often fall within this category.

The Technical Council on Lifeline Earthquake Engineering of the American Society of Civil Engineers¹ has identified four major types of lifelines: 1) electric power and telecommunications, 2) gas and liquid fuels, 3) transportation, and 4) water and sewage. Table 1 lists each system with associated line components and support and terminal facilities. A brief reading of the table will show the wide range of structures and services covered by lifelines.

There are several distinctive features of lifeline systems. Because they cover large areas, they must extend over a wide variety of soil and rock conditions. An individual building occupies a relatively small area and can be located or characterized by means of a focused evaluation of seismic and ground failure hazards. In contrast, line structures extend for many miles and frequently must follow rights-of-way that are constrained by law or property ownership so that seismic and ground failure hazards cannot be avoided.

Lifelines are interconnected; they are parts of networks which involve different pathways, vulnerable components, and opportunities for changes depending on system characteristics and the risks associated with their different parts. They are well suited for systems analysis, which involves decisions based on principles of probability and reliability. Lifelines are interdependent; damage in one system

¹Technical Council on Lifeline Earthquake Engineering, "Advisory Notes on Lifeline Earthquake Engineering", American Society of Civil Engineers, New York, NY, 1983.

Table 1. Summary of Line Components and Support and Terminal Facilities for Lifeline Systems.

Lifeline System	Line Components	Support Facilities	Terminal Facilities
Electric Power and Telecommunications	Overhead lines, buried cables, offshore, cables, and tunnels.	Electric substations, telephone equipment buildings, radio transmission towers, and computers.	Power plants, including fossil fuel, nuclear, and hydroelectric developments.
Gas and Liquid Fuel	Subsurface and elevated pipelines, including continuous welded, jointed, and bolted pipelines.	Pumping stations, regulator stations, storage tanks, and underground storage facilities.	Oil and gas fields, and port facilities.
Transportation	Highways, secondary roads, railroads, rapid transit lines, bridges, and tunnels.	Railroad and rapid transit stations, retaining structures, and embankments.	Harbors and airports.
Water and Sewage	Subsurface and elevated pipelines, including continuous welded, jointed, and bolted pipelines; irrigation culverts and aqueducts, and tunnels.	Storage tanks, wells, and pumping plants.	Reservoirs, earth and concrete dams, and wastewater treatment works.
1 Based on lifeline categories used by the Technical Council on Lifeline Earthquake Engineering (1983)			

may affect the performance of another. The rupture of gas or liquid fuel lines may be a source of fire, which must be considered in the post-earthquake use of water distribution networks. Simultaneous breaks in water and sewage lines may pose a health hazard through contaminated drinking water. Loss of electrical power may affect pumping stations for water, thereby limiting the amount of water and placing greater emphasis on the transportation system for emergency repairs.

3.0 EARTHQUAKES IN THE EASTERN UNITED STATES

Earthquakes occur less frequently in the eastern United States than they do in the western parts of the country. As a consequence, there is less concern about earthquakes in the eastern states. This level of concern follows from a relatively low level of earthquake activity. It is justifiable to think of the eastern United States in terms of diminished risk for the occurrence of a serious earthquake. Nevertheless, this thinking must be tempered by considering the consequences of a serious earthquake. Although earthquakes occur less frequently in the eastern states, the potential for damage from a major earthquake is more severe.

Scientific and engineering studies have shown that the potential for a major earthquake exists in some parts of the East. Figure 1 shows a map of 48 states on which are superimposed zones illustrating the seismic intensities experienced during previous earthquakes². The intensities are mapped according to a standard scale, called the Modified Mercalli scale, in which earthquake damage increases in proportion to the number of the scale. The dark areas are intensity VIII and greater; the light areas are intensity VI-VII. An intensity VIII corresponds to considerable damage in ordinary buildings, with fallen walls and chimneys and signs of soil liquefaction. The most striking characteristics of the figure are the large areas of high intensity

²Algermissen, S. T., An Introduction to the Seismicity of the United States, Monograph Series, Earthquake Engineering Research Institute, Berkeley, CA, 1983.

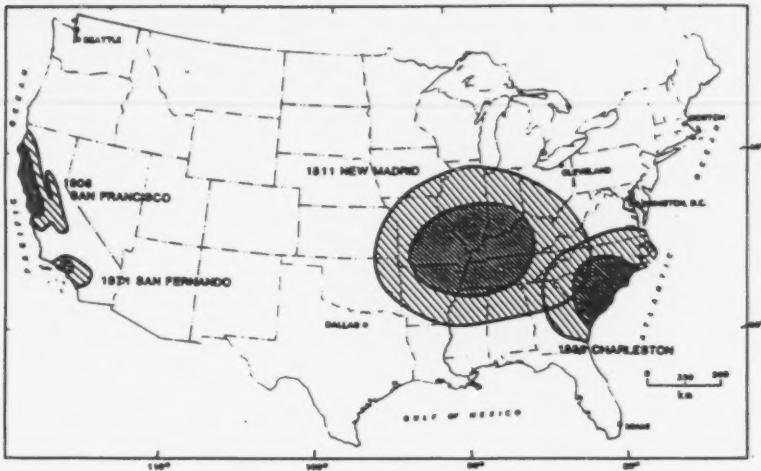


Figure 1. Map Showing Areal Distribution of Earthquake Intensities (after Algermissen, 1983).

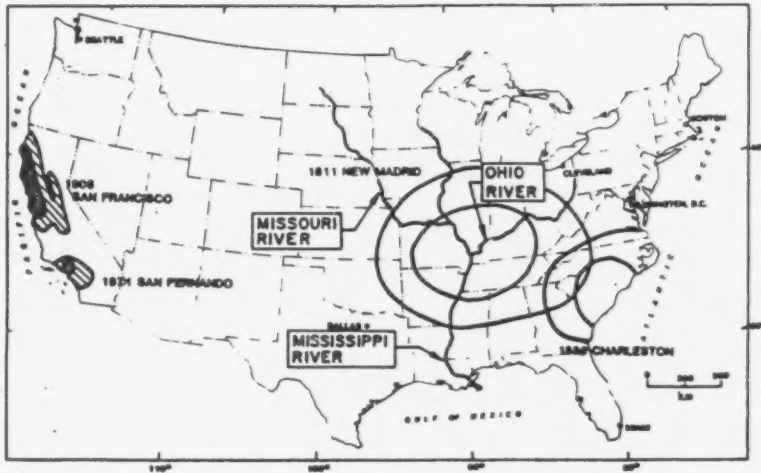


Figure 2. Map Showing Center of Earthquake Intensity Affecting Soils Along the Major River System of the United States.

for the eastern United States associated with the 1811 New Madrid and 1886 Charleston earthquakes. In terms of earthquake magnitude, M_s , the New Madrid earthquake had an estimated $M_s = 8.6$ compared to an estimated $M_s = 8.3$ for the 1906 San Francisco earthquake.

Figure 2 shows that the center of intensity for the New Madrid earthquake occurred near the confluence of the Mississippi, Ohio, and Missouri Rivers. The soil conditions in this area are associated with flood plain deposits and buried channels, which are highly susceptible to liquefaction. Soil liquefaction occurs when ground shaking increases the water pressure in saturated sandy deposits with a corresponding loss of shear strength so that the soil responds as if it were a liquid. Soil liquefaction has been recognized as a major factor affecting damage during and after earthquakes. There is substantial evidence of widespread liquefaction during both the New Madrid and Charleston earthquakes.

The earthquake performance of lifelines is closely associated with permanent ground movements, especially those caused by soil liquefaction. Lifelines frequently are buried so that the ground is an integral part of their structure. There are few pipelines that are sufficiently large and reinforced to resist permanent movements of the surrounding soil mass without substantial deformation. The performance of highways, rail lines, and waterfront facilities depend on the behavior of man-made fills and natural soils.

The most serious liquefaction hazard for buried pipelines is lateral spreading. This phenomenon results from soil which liquefies beneath a layer of intact soil, causing the intact soil to deform. Lateral spreading can occur on slopes with inclinations as small as 0.5 degrees and can involve movements as large as 10 to 20 ft. Figure 3 illustrates a pipeline deformed by lateral spreading. Large abrupt displacements can occur along the margins of a lateral spread which will impose locally high levels of earth pressure and distortion on the buried pipe.

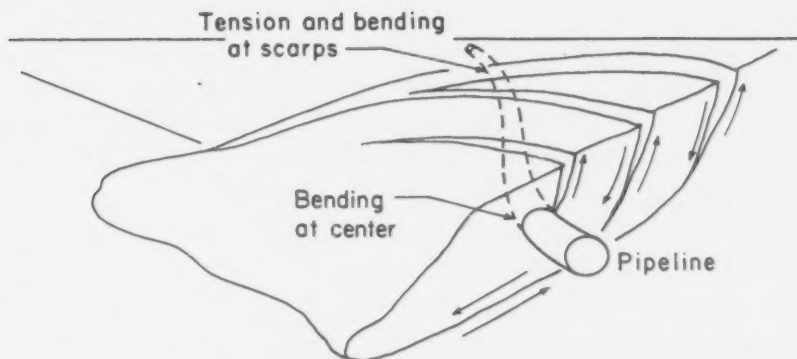


Figure 3. Three-Dimensional View of Lateral Spreading and Its Influence on a Buried Pipeline.

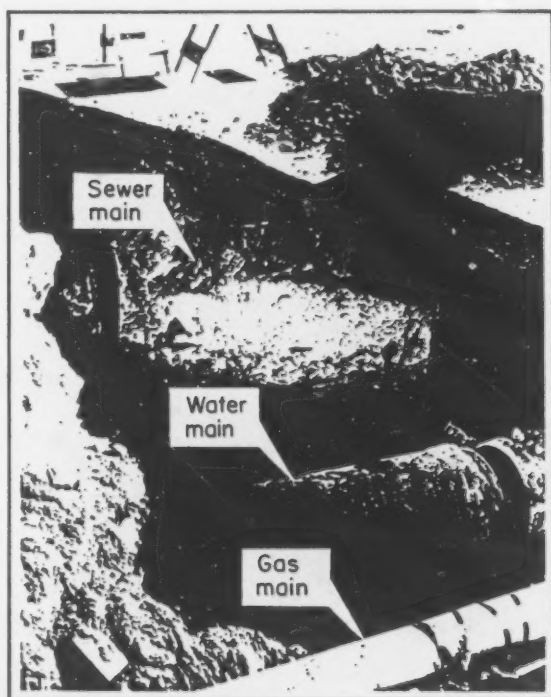


Figure 4. Damaged Water, Sewer, and Natural Gas Pipelines in Area of Permanent Ground Movement after the 1971 San Fernando Earthquake.

As rights-of-way become more restrictive, it is increasingly more common to find several different lines (even at high pressures) within the same corridor. Figure 4 shows damaged water, sewer, and gas pipelines in an area of permanent ground displacement after the 1971 San Fernando earthquake. The consequences of pipeline damage can be compounded by multiple failures such as these. Water from ruptured water mains can wash flammable liquids downgrade. Broken electric lines can ignite gas from ruptured natural gas lines.

4.0 MEASURES FOR EARTHQUAKE MITIGATION

As previously mentioned, improvements in lifelines for earthquake response generally result in better system performance under normal operating conditions. For areas where there has been a low awareness of earthquake hazards, there are simple measures that can be incorporated in lifeline design and operation which involve little additional expense and can be justified by benefit/cost analysis in terms of increasing system quality.

Improvements in pipeline systems, for example, starts with the recognition that permanent ground movement represents the most severe threat to the integrity of buried mains and that mass movement of the ground is very difficult to resist. It follows therefore that the most effective designs are those which provide for flexibility and ductility in the pipeline so that it can accommodate large displacements without disruption.

Areas where flexibility is most needed occur at connections between pipelines and larger, more rigid structures. Examples include penetrations and tie-ins at pump stations, special valve structures, storage tanks, and bridge abutments. Often, the provision for additional flexibility at these connections involves a relatively minor change in the structural and pipe fitting details around a penetration. Flexible designs must also ensure continuity between the pipe and structure.

Pipelines, which are composed of continuous ductile steel and protected against corrosion, are among the strongest and most resilient structures during an earthquake. There is little evidence during North American earthquakes of significant damage to butt-welded transmission pipelines constructed according to modern practices. Continuous steel pipelines with quality welds have performed well even when subjected to large differential ground movements. A key factor is to site these structures to take advantage of their capacity for tensile deformation. In areas of potential permanent movement, it is helpful to lay the pipeline in relatively straight sections taking care to avoid sharp changes in elevation and direction. To the extent possible, the pipelines should be constructed without bends, elbows, tie-ins, and curvilinear joints that lead to eccentric loading. Orientations that promote pipe compression from soil movements should be avoided. A shallow depth of burial is also helpful.

Previous earthquake experience has shown that several types of pipelines are especially vulnerable to earthquake disturbance. These pipelines often are associated with maintenance problems during normal operation. Accordingly, the identification and replacement of these lines carries benefits for both increasing earthquake resistance and decreasing problems in long-term operation. Some steel pipelines constructed before and during the early 1930's are susceptible to damage as a result of welding practices which did not benefit from the same welding practices that prevail today. The date of 1932 can be taken as an index, and pipelines constructed before this time should be reviewed in terms of maintenance records and weld quality to make a better judgment of potential risk. Water pipelines constructed during the 1920's of Mannesman or Metheson steel are susceptible to corrosion and earthquake damage. Likewise, galvanized steel mains have shown increased vulnerability at threaded connections where the cross-sectional area is reduced and the galvanized coating tends to be stripped.

5.0 FUTURE WORK

Future work in lifeline earthquake engineering should concentrate on the implementation of research and field studies already performed and on research dealing with geotechnical hazards and the systems performance of lifeline structures. There are many valuable lessons, which already have been learned, that can be applied at little or no cost to lifeline facilities in the East. Regional seminars, special conferences, and short courses provide opportunities for educating utility and transportation engineers about earthquake hazards and low cost ways of improving component and system performance. Educational activities are most effective when suitable publications are available that summarize the subject area and provide a working document for future use. Guidelines and advisory notes produced by engineering societies help greatly in this regard.

Research and better awareness of geotechnical hazards are needed, especially with respect to soil liquefaction in the eastern United States. In the past twenty years, much valuable work has been performed on liquefaction. The earthquake forces, soil conditions, and water table characteristics associated with liquefaction are generally understood. For lifelines, however, it is generally not sufficient to know if liquefaction may occur, but what form the liquefaction-induced soil movements will take. This area involves consideration of soil type, ground water, landforms, topography, and geologic structure.

Because lifelines make up networks, they can be analyzed as systems. Systems analysis uses probability as a tool for evaluating the likelihood of local and system-wide failure. It can provide a sound basis for decisions about new construction, maintenance, and retrofitting. Most importantly, systems analysis can be used to test various earthquake scenarios and develop a plan for emergency response that best fits the characteristics and expected disruption of the system. With the rapid growth of computer technology, there are excellent opportunities for developing interactive models which will allow utility engineers to experiment with different earthquake effects and choose appropriate strategies based on projected costs relative to preservation of life and property. The development of these analytical models must proceed hand-in-hand with input from practicing engineers, who understand the physical characteristics and operational constraints of real lifeline systems.

Mr. GORE. Great. Thank you very much. We certainly appreciate your statement.

Dr. Schiff and Dr. Oppenheim, I'm going to ask your patience. We have a vote on the floor; it won't take long. We're going to recess, with your indulgence, for about 8 to 10 minutes; and then we'll be back over here and resume, and we'll finish up the hearing, and hopefully your stomach won't growl too much, because I know it's getting close to lunchtime.

We'll recess for 10 minutes.

[Recess.]

Mr. GORE. We'll come back to order. I apologize to our final two witnesses, and we certainly appreciate your patience and forbearance.

Our next witness will be Dr. Anshel Schiff, professor in the Department of Mechanical Engineering at Purdue University.

We appreciate your presence here, and please proceed.

Dr. SCHIFF. Thank you.

What I'll be talking about today is reference to power and communication systems, two of the lifelines that were referred to earlier, and, in particular, talking about past performance, anticipated seismic response, and research needs, with a focus to the Eastern United States. In particular, I will be focusing on a New Madrid type of event—in other words, a great earthquake in the Midwest.

Reviewing past performance of power systems, power systems can be divided into four major elements: generation that generates the power; the transmission system that moves large blocks of power in different regions; it's a highly redundant network of both lines and substations; the distribution system, which is in a sense similar to the transmission system that operates at lower voltages, tends to have a portion which is redundant network and also feeder lines which are nonredundant; and then the control system of the entire system.

Reference to the performance of generating plants to date have been rather good. However, that performance has been measured primarily by earthquakes in California and in Japan.

To date, no coal-fired plant has been subjected to an earthquake, and the plants—the oil- and gas-fired plants, which tend to be much smaller for the equivalent power rating than a coal-fired plant, have been small plants, to boot, typically being less than one-tenth of the size of a modern coal-fired or gas-fired plant.

Reference to the transmission system, most of the—they consist of the lines and of the substations. The performance of the lines have been quite good to date.

Most damage to power systems, indeed, has been to the substation equipment. I have a few slides to illustrate some of the damage that has occurred. I've also provided to you a picture book that was prepared under National Science Foundation support addressing low-cost measures that can be taken to improve the earthquake response into areas such as the Midwest, and that is directed specifically at the Eastern United States.

Briefly, some pictures.

[Slide.]

Dr. SCHIFF. These are pictures which I took in Japan one month after the Sendai earthquake. If you notice that the—the large vertical columns.

[Slide.]

Dr. SCHIFF. The next shot is a poor quality shot because it's a blow-up of a picture which I took of their pictures, and so it's not a clear picture.

You notice what was vertical columns in the last shot are now horizontal columns.

[Slide.]

Dr. SCHIFF. Again, a 255-kv circuit breaker. It turns out that the high voltage equipment in 255 kv is not particularly high voltage, is much more vulnerable than the lower voltage.

[Slide.]

Dr. SCHIFF. And then this is the shot that they took immediately after the earthquake.

[Slide.]

Dr. SCHIFF. Here's another general shot just giving you some indication of the damage which occurred.

Now this occurred in Japan, where they are quite cognizant of the earthquake problem, and the seismic design for these substations was substantially higher than what is used in the Midwestern United States.

[Slide.]

Dr. SCHIFF. Here we have a transformer where you can see the major damage has been to porcelain rather than structural steel or other parts of the equipment, but the porcelain elements of the equipment.

[Slide.]

Dr. SCHIFF. We don't have to go to Japan to see damage, however. Here's the San Fernando Valley earthquake. Transformers have rolled off their skids. This is the typical way which transformers are mounted in the Midwest today. The older transformers are still mounted this way and are not secured.

[Slide.]

Dr. SCHIFF. Circuit breakers—again, this is San Fernando damaged equipment.

[Slide.]

Dr. SCHIFF. But we don't have to go back that far. April 24 of this year was the Morgan Hill earthquake. This site occurred some 80 miles from the epicenter. Acceleration levels at this site were about 5 percent g, and here we can see one of four circuit breakers at this site that were totalled. Additional circuit breakers were damaged but remained functional.

[Slide.]

Dr. SCHIFF. OK. So this indicates that indeed we have a substantial history of power system damage to small and moderate size earthquakes, damage occurring from low level to rather severe vibration inputs.

It turns out that the high voltage is more vulnerable. It also turns out that it is more important because it carries large blocks of power.

The distribution system has also experienced some damage to their substations, and there has been some damage to feeder lines

burning down and pole transformers falling. However, while this may cause wide disruption of power, it tends to be relatively local and therefore is not as detrimental.

[Slide.]

Dr. SCHIFF. Control system effects have been—the effects—we've had some damage, but the results have not been too significant as far as system response.

Here we show a control room, and it's very common to have ceilings come down in control rooms. Obviously, the control room is not too functional, but the actual damage looks more severe than—than its functional effects.

[Slide.]

Dr. SCHIFF. Here we have a picture of computer damage, and one of the aspects where there's a question which remains unresolved is for the control systems which are becoming more computerized in the future, as to what will be the effect of damage to computer systems.

Relative to power systems then, to summarize, there are several questions which remain unanswered. We do know that there has been extensive, repeated damage to power facilities. We do know that they are redundant systems to date.

System performance has been good. The question is, in the Midwest, will there be sufficient damage over a large area that the redundancy will be overwhelmed and that we will get a poor system performance.

There are a lot of buried lines. Performance has been good to date in the neighborhood areas. The question remains in the—with the extensive liquefaction that we expect in the Midwest, whether the future performance will be as good as the past performance.

Also, the questions on secondary effects. Modern society is becoming ever—increasingly dependent on electric power, and the disruption of that electric power on various facilities, other lifelines, and other noncritical facilities remains—these questions remain unanswered at the present time.

Relative to communications systems, response so far to communication systems has been very good. With every earthquake, we do have an overload, just with people making calls. In the Midwest, this may cause some difficulties in that automatic control systems lock out outside calls from coming in.

In the Midwest, the area may be so large that each local community can call within its own areas, but there will be really disruption of communications between damaged areas not being able to respond to emergency response.

[Slide.]

Dr. SCHIFF. There is one example of a serious failure, and that's shown here. This is the inside of a switching center in San Fernando. It's equipment failure. The structure behaved acceptably. As a result of that, there were improved specifications.

One of the unanswered questions is whether the improved specifications instituted by Bell Labs as a result of this have—where they've really been adopted in the Midwest and Eastern part of the country, or can we expect this type of performance in the future.

There's also the question of buried lines, and there's a big question today with the divestiture. There's been many new smaller

companies coming in with very good innovative electronic gear to meet the market demand. It's not clear, however, whether the traditional mechanical design of these equipments will be as good as which we experience from Western Electric under the Bell system.

There's also new facilities in the sense of optical fibers, that we don't know how their performance has been, although buried lines to date for the communications system has been good.

When it comes to prediction—so we have—to summarize, power systems performance has been very sketchy when it comes to high voltage substations, communications systems, with the one exception noted—has been pretty good.

When it comes to predictions, we really have to translate the California and Japan experience into the Midwest, and we have to note certain differences. These have been alluded to earlier, and I'll just comment, one, that the—we have no seismic requirements, by and large, applied, for instance, to power systems in the Midwest, so that very little bid is done relative to earthquake effects within the Midwest relative to power systems.

Since practice in specifications are lower, we can expect more damage in the Midwest than we expect—that we have experienced in California, and that experience has not been particularly good. So we can expect more damage.

The low attenuation of seismic waves in the Midwest also means that a larger area is going to be subjected to severe shaking, and longer duration vibrations are going to be experienced than what we've noted to date.

The result is that the inherent redundancy and reliabilities designed in power systems may be overwhelmed, and indeed we may have poor system performance, which we have not experienced to date.

Also, as was in the last talk alluded to, liquefaction. Powerplants typically are located adjacent to bodies of water, and there is a problem of liquefaction, particularly of the turbines.

Differential liquefac—differential settlement of turbine foundations as much as one to two hundredths of an inch will make the turbine nonfunction and will have to be releveled, and there's a—we may see much more liquefaction disruption of power plants than we have observed in the—in California.

Another factor which has not come into the equation in responding to earthquakes in California is the possibility of winter weather.

Inclement weather in California means you put on your windbreaker and go out and do your service. However, in the—if a severe earthquake should occur in winter, the impact on restoration, and particularly the loss of all residential heating due to the loss of power may have very significant impacts on—on the effects of the loss of this particular lifeline.

In projecting what might happen to—in a great earthquake in a modern urban area, it must be emphasized that we—one must wing it, so to speak, in the sense that we have no experience worldwide of a major great earthquake in a modern metropolitan area.

However, projecting—and here's really one of the needs of research which I'll refer to in a minute or two—is that there is

damage to—there is the possibility of damage to generation facilities, which may limit the availability of power for several weeks.

More important is the damage to the transmission system, because we have ample damage of this occurring repeatedly on the west coast and other areas which are aware of seismic hazard.

In the Midwest, we have more high voltage equipment, and we have 765 kv equipment, which doesn't even exist in Japan or California, which is, indeed, more vulnerable. So we can expect possible large areas without power, possibly as much as 2 or 3 weeks, where there would be large areas of—of communities without power.

Damage to the distribution system—we could expect that to be restored over many, many weeks, and—but this would be relatively local effects that would occur.

Relative to communication systems, performance has been good, but there's another question relative to communication systems in that there are specialized communication systems, particularly the banking industry.

Disruption of any major banking center would not only disrupt the financial community of the United States, it would be a major disruption to the entire free world economy, and there a disruption of 1 or 2 days starts to be catastrophic in its effect, and so the sensitivity of these computerized communication systems is, again, very questionable, or its impact would be very large; its earthquake resistance is very questionable.

To summarize research needs, therefore, there is a clear, important need for improved earthquake resistance of high voltage power equipment.

There's a need for large-scale testing facilities, and to the use of these facilities to better understand how equipment responds in a generic sense, not just testing equipment to see that it's earthquake-resistant, which is often what's done for nuclear facilities, but an evaluation to get a better understanding of how this equipment really responds.

A second area—secondary effects, which is really crucial—there's two aspects of secondary effects which have not been addressed. First of all, there's the critical facilities for emergency planning and emergency response community.

How are other lifelines, particularly communication and power, but other lifelines affected—hospitals, police stations, fire stations? The loss of these lifelines, how will that affect those particular facilities?

Another area is the societal impacts for secondary effects. By and large, this—nothing has been done in this area to, in a systematic way, looking at the safety, economic impacts, and industrial impacts of a major area when we are subjected to a very large earthquake.

Other questions which need to be answered is, how does one get lifeline managers to address the societal needs? If a lifeline manager looks at the direct costs of his system—might be different judgments to the impact if there is gross disruption of that service to the community, which might mandate higher earthquake resistance than would be justified just from the direct loss of the equipment. By and large, society has not addressed those—these questions.

How do complex—and this has been alluded to earlier—how do complex systems respond to earthquakes? There are highly redundant systems, they're spread over a geometrical—geographical areas, and it's—there's questions on how to model and accurately and economically characterize these systems for both planning, for emergency planners, and also the utilities themselves.

How does one motivate local utilities to implement measures that we know? There are a lot of simple, low-cost things that are justified, that we can do in the Midwest, that by and large are not being done today, and so there is—needs to be research and to figure out how to get local lifeline people to implement those things which are known.

Finally, there is a need for emergency response, and lifelines' impact on emergency response. The low preparedness within the Midwest really mandates that the emergency response community must address disaster when it occurs, and the disruption of power systems, communication systems, and other lifelines will greatly impede the emergency response community, and these particular questions have not adequately been addressed.

Thank you very much.

[The prepared statement of Dr. Schiff follows:]

TESTIMONY OF PROFESSOR ANSHEL J. SCHIFF BEFORE THE JOINT HEARING
ON DAMAGE PROJECTIONS OF FUTURE EASTERN EARTHQUAKES
SEPTEMBER 12, 1984

INTRODUCTION

Lifelines, usually taken to include electric power, communication, water, sewage, gas/oil, and transportation systems, have derived their name from the fact that a community in a modern industrial society can not long survive without the services provided by these systems. Their disruption would constitute a major disaster in its own right. In the aftermath of a major earthquake, their damage will significantly add to the direct losses caused by the earthquake and their disruption will exacerbate emergency response efforts. While it would be desirable to have these systems perform in a manner that balances the cost of earthquake mitigation with the acceptable risk of disruption, as a minimum, their anticipated response should be known so that it can be incorporated into emergency response planning.

This testimony will focus on communication and electric power systems, emphasizing the latter. The earthquake resistance of these lifeline facilities will be discussed, followed by an estimate of what system performance might be expected after a major earthquake. Finally, research needed to address the problems will be discussed.

EARTHQUAKE RESISTANCE OF POWER AND COMMUNICATIONS SYSTEMS
IN THE EASTERN UNITED STATES

The earthquake performance of elements which make up power and communication systems will be reviewed and the impact of their damage will be discussed. Power systems can be divided into four major elements; power generating plants, the power transmission system, the power distribution system, and the control system.

Power generating plants have performed fairly well to date. However, no coal-fired plant has been subjected to a significant earthquake and the oil-fired and gas-fired plants that have experienced earthquakes have been about 1/10 the size of modern plants. The loss of the power output from any single plant can generally be accommodated, as plants must periodically be taken out of service for maintenance, although this would normally be done at off peak power demand times of the year. Should several plants be lost, sufficient spare capacity may not be available in the region to meet total demand or the transmission system may not be able to deliver the needed power.

The crucial link in a power system is its transmission system. The transmission system consists of high voltage power lines and substations. Systems have been designed to be highly redundant to enhance their reliability. Most systems have several operating voltages, ranging from 138 kv to 760 kv. The seismic performance of power transmission lines has been very good. Most damage to power systems has been to high voltage substation equipment. Even in regions of high seismic awareness in both the US and Japan there has been significant substation damage to high voltage equipment from low to moderate shaking from small to moderate earthquakes. Unfortunately, it is this equipment that carries the most power and is the most important to system operations. To date, earthquake shaking has been localized so that damage has been concentrated at a few facilities and system redundancy has yielded an acceptable system response.

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The power distribution system consists of distribution substations, overhead lines, buried lines and pole transformers. Distribution substations which have lower voltage equipment have experienced some damage, but they are more robust than transmission substations. Distribution lines, set in motion by the earthquake, will come in contact, burn down, and create a safety and fire hazard. In the east, pole transformers improperly mounted to resist earthquakes can fall causing disruption. While buried distribution lines have performed well to date, their earthquake exposure has been limited. The effect of distribution system damage is to cause local disruption of service. Because the distribution system is so large, extensive damage will require lengthy restoration times.

The final element of power systems to be considered is the control system. Damage experienced to date has been the failure of control room ceilings and damage to computer terminals after they fell from their desks. Clearly, the unavailability of the control room or the failure of its computers after an earthquake could cause severe system damage and disruption.

The performance of communication systems has generally been good. There was a major failure of telephone switchgear due to inadequate bracing in the 1971 San Fernando earthquake. Buried lines which are used extensively have performed well. Newer electronically based equipment and optical fiber transmission lines have not experienced much seismic exposure yet, so their performance is untested.

PREDICTED LIFELINE RESPONSE TO A GREAT EASTERN EARTHQUAKE

Several differences must be taken into account when attempting to translate California's earthquake experience to an occurrence of a great earthquake (Richter Magnitude above 8) in the eastern US. The long interval between major eastern earthquakes means that this region is less aware of seismic hazards and that the cost of mitigating the hazards must be less if the effort is to be cost-effective. The absence of seismic elements in building codes and the fact that even simple measures to improve seismic design are often not practiced means that the performance in the east can be expected to be poorer than in California.

Other differences in the seismic hazards in the east suggest that the extent and duration of disruption can be expected to be more severe. Less attenuation of earthquake-induced seismic waves means that a much larger area will be subjected to severe ground shaking. Thus, more facilities can be expected to be damaged so that the redundancy designed into lifelines to improve system reliability may be overwhelmed, yielding poor system performance. The smaller attenuation, the large size of the postulated event, and other factors means that the duration of severe shaking will be longer than experienced to date in California. Facilities observed to have been stressed to their limit in California from lesser earthquakes may fail under the postulated event. In the east, most major cities have developed adjacent to rivers or lakes where the high water table and soil conditions are more conducive to soil liquefaction than is commonly experienced in California. Liquefaction is a condition in which soil loses its bearing strength and may flow like mud. Finally, the impact of severe weather, should the earthquake occur during severe winter conditions, would not only exacerbate restoration efforts but the loss of all residential heating resulting from the loss of electric power would require a massive rescue effort to save elderly people whose normal metabolism must be supplemented with external heating.

The impact of these conditions on power systems in the east is that several power generating plants over a wide area may experience problems due to soil liquefaction and severe long duration vibration. Since the seismic response of power generating facilities has been good to date, it is difficult to estimate restoration times, but releveling turbines due to differential settlement and the repair of other damage may limit the availability of power for many weeks. Probably the most important element of the system is the integrity of the power transmission system. Equipment in transmission substations has proved to be more vulnerable to damage the higher its operating voltage. The east has more 500 kv substations than the west and it has facilities operating at 760 kv that are not even present in the west. The amount of equipment that can be expected to be damaged, the limited supply of spares, and the amount of time required to repair this equipment means that some regions may be without power for extended periods, say two to three weeks. Extensive damage to the distribution system can be expected. The increased use of buried utilities in residential areas in recent years coupled with the expected liquefaction may cause more widespread disruption than experienced to date. The restoration of buried facilities is also much more labor intensive than for overhead lines. While restoration times may extend for weeks, the fact that the disruption from distribution system damage tends to be localized reduces its impact.

The response of communications systems is more difficult to predict. As a result of the failure of a local switching office in 1971, improved installation specifications were developed. The extent to which these specifications have been used in the east is not known. Several recent developments complicate predicting the system response. The increased use of optical fibers for communications introduces a new technology that is unevaluated relative to its earthquake response. In general, one would anticipate that the good performance of traditional transmission cables would carry over to optical fibers, however, optical fibers will fail in tension before its copper counterpart. The second uncertainty is associated with the divestiture of the local operating companies by American Telephone and Telegraph. New manufacturing companies with innovative products have been stimulated by the opening of the market to the operating companies. It is not clear that these new products will be given the same care in their seismic design that they received when they were developed by AT&T. As with buried power cables, the effect of widespread liquefaction in the east is not known. There has also been an increase in the centralization system control. Should one of these facilities fail major disruptions could occur.

An increasingly important part of communication systems are the data/information networks that are emerging. Some of these systems are relatively specialized, such as the system used by the banking industry. Even short term disruption of these systems will not only impact the entire US economy but will impact that of the entire free world. They all are highly dependent on computers, and their response in real operating environments which include their support systems are largely untested.

It should be emphasized that no urban area in a modern industrial society has been subjected to a great earthquake so it is difficult to predict the consequences of such an event. The fact that there has been extensive damage to these facilities from moderate earthquakes would support the projections of extended disruptions. These rough projections of lifeline disruption, which should be supported by research as noted later, may be overly pessimistic. In light of the increasing pervasiveness of these systems in today's communities and the lack of information on the impact of secondary effects resulting from their disruption, the projected disruptions may also be underestimated.

RESEARCH NEEDS

Only some of the most important research needs will be addressed here. Relative to power systems, past poor performance clearly identifies several pressing needs. There is a vital need to improve the earthquake resistance of high voltage substation equipment through research in improved materials, better configurations or the use of base isolation methods. Closely related to this is the lack of large scale testing facilities and the reluctance to commit funds to research involving testing, in part, because of its high cost.

Many research areas are common to both power and communication systems. There is a need to better identify secondary effects associated with the disruption of these lifeline services. Research directed along two avenues is required. One, focusing on secondary effects that will impact the emergency planning community would emphasize the effect on critical facilities such as hospitals, emergency response centers, and police and fire support facilities. The second focus would be on more general societal impacts such as economic losses and the effects on industry. There is a need for identifying societal needs and motivating managers of such systems as lifelines to incorporate them into their system planning. There is a need to better understand how complex systems will respond to earthquakes. This is particularly true with regard to the operation of increasingly automated control systems and information systems that are highly dependent on computers. Control systems are tending to become increasingly centralized. This is counter to the principle of redundancy to improve system reliability extensively used throughout the rest of the system. There is a need to develop methods to stimulate the implementation of methods that will improve the earthquake response of these systems.

Finally, it must be realized that it is impossible to make these systems and the structures within society in general earthquake "proof" so it is vital that the society be able to response to an earthquake when it does occur. In the eastern US, where the level of preparedness is so low, emergency response is particularly crucial. Power systems, the lifeline to other lifelines, and communication systems play such a vital role in the post-earthquake environment that in addition to preparedness there should be a major thrust to earthquake mitigation. In this regard, government facilities could set an example by following good seismic design practices.

PERSONNEL

Anshel J. Schiff

Education:

B.S.M.E.	1958	Purdue University
M.S. (Engr. Sci.)	1961	Purdue University
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Professional Experience:

Instructor in the School of Aeronautics, Astronautics, and Engineering Sciences, September 1959 to September 1967.

Assistant Professor of Aeronautics, Astronautics and Engineering Science, Purdue University, 1967-1972.

Associate Professor of Aeronautics, Astronautics and Engineering Science, Purdue University, 1972-1973.

Associate Professor, School of Mechanical Engineering, Purdue University, 1973-1978.

Professor, School of Mechanical Engineering, Purdue University, 1978-present.

Member, Earthquake Safety Subcommittee, Elevator Code Committee, American National Standards Institute A17.1, 1977-present.

Member, Strong Motion Instrumentation Committee, Earthquake Engineering Research Institute, 1975-present.

Chairman, Strong Motion Record Analysis Committee, Earthquake Engineering Research Institute, 1983-present.

Member, Shock and Vibration Committee, Applied Mechanics Division, American Society of Mechanical Engineers, 1974-1981.

Member, Technical Council on Lifeline Earthquake Engineering (TCLEE), Committee on Electrical Power and Communications, 1976-present, Chairman 1983-present.

Panel Member, Technical Advisory Panel, Regional Director's Advisory Committee, Region VII, Federal Emergency Management Agency (1983).

Director, Center for Earthquake Engineering and Ground Motion Studies, Institute of Interdisciplinary Engineering, Purdue University, 1980-present.

Member, Senior Seismic Review Advisory Panel, Seismic Qualification Users Group - Nuclear Regulatory Commission, (June 1983-present).

Member, Indiana Civil Defense Earthquake Program Advisory Panel, (February 1983-present).

Member, ASME, ASCE, EERI, ISA, ASEE, SIGMA XI, AAAS, PMA, and AAN.

Research:

"Strong Motion Seismograph" - Investigation, NSF, April 1, 1967-March 31, 1971.

"Strong Motion Seismograph Design," NSF, May 1, 1970-October 31, 1971.

"Response of Electrical Systems to the San Fernando Earthquake of February 9, 1971," NSF, June 1, 1971-May 31, 1972.

Determining Dynamic Structural Response," NSF, January 1, 1972-June 30, 1974.

"Acquisition of Psychomotor Skills in Dentistry," Public Health Services, January 1, 1973-August 31, 1974.

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Mr. GORE. Thank you very much. We certainly appreciate that fine statement.

Dr. Oppenheim, we're delighted to have you here as well. We've got another vote on the floor, I'm sorry to say, but we can get into your statement for a few minutes, and then we'll have to recess for 8 to 10 minutes, and then we'll come back and finish it up. If you want to proceed, please do.

Dr. OPPENHEIM. Thank you, Mr. Chairman.

I'd like to address the following questions: Are lifeline systems in the East at some particular risk? can we compare their exposure to systems in California? and, do we stand to benefit from further research and investigation?

In my research, we have attempted to measure the economic loss to a region as the result of earthquake damage to a lifeline system.

Now lifelines are distinguished by certain key properties which are pertinent to a discussion of damage projection in the East. Such properties include storage, redundancy, and user preference, and these properties can diminish or magnify user loss. I would like to discuss them briefly.

Starting with storage, there are lifelines that contain a quantity of their commodity in storage. An aqueduct may fail, but a reservoir at its terminus may hold a several-months' supply of water. The regional users feel no impact as long as that stored capacity can supply them. In other words, storage provides a buffer in time in which the impact can be eliminated while repairs are made.

Similarly, redundancy refers to a multiplicity of paths through a network. There exist street systems which are laid out on a very regular pattern such that arteries can be destroyed, yet users still can function through the system.

In contrast, other urban areas funnel a large number of users through very few bridges or tunnels. Such bottlenecks represent minimal redundancy, and user losses would be magnified.

User preference refers to the fact that individual users make choices in drawing upon the services or commodities of a given lifeline.

For instance, users can eliminate or reschedule automobile trips. We can cut down the number of trips we make in our household in the course of a day as a result of poor availability of the transportation network.

The most profound way in which user losses are, in fact, contained is by the good commonsense of the individual citizens out there in drawing on its use. It's important to understand this, because this gives local authorities the best understanding to manage operations in the wake of an earthquake or any other disaster, for that matter.

I'd like to compare Western and Eastern damage expectations—

Mr. GORE. Could I ask you to—that looks like a good breaking point.

Dr. OPPENHEIM. Sure.

Mr. GORE. And we'll be back, and—we'll recess for 10 minutes and come back, and I'd anticipate finishing up the hearing fairly quickly. I appreciate your patience.

[Recess.]

Mr. GORE. The subcommittees will come back to order.

Again, I apologize for the delays. Please understand that during the final days of a 2-year congressional session, a lot of important votes are scheduled during times when committees are meeting, and it's difficult, but just bear with us.

You were down at the bottom of page 3 of your statement, I believe, Dr. Oppenheim. If you care to continue, please do so.

Dr. OPPENHEIM. Thank you, Mr. Chairman.

In comparing lifeline losses in the East and in the West, it appears that eastern cities may be more susceptible.

Many eastern cities are shaped by rivers and hills, which will create bottleneck conditions in the network. Their street systems—their older street systems may be irregular and narrow, and such a system could display losses greater than those suffered by a comparable system in the West. Of course, the nonresistant construction employed in the East would further lower the threshold for that damage.

The lifeline damage can also present a danger to regional productivity, especially in those areas which contain no growth or retracting industries. Disasters often provide the impetus for overcoming some of the inertia for undesirable decisions that get put off, but are looming on the horizon.

For instance, certain industries closed operations in Johnstown, PA, rather than reopen in the aftermath of a storm flood in this past decade. In contrast, there was severe damage in Anchorage, AK, in 1964, but it was followed by full rebuilding and expansion.

We have to recognize that the impact of a natural disaster will be quite different in an area which faces a mix of growth and decay trends, as compared to an area that has robust growth.

Finally, regarding the benefits of further study, in my estimation, lifeline damage in the East is a nonnegligible component of the overall seismic risk facing the Nation and should logically warrant some appropriate portion of the Nation's effort.

I'd like to point out that lifeline studies could offer some real benefits, precisely because lifeline systems are managed and used by humans.

I'd like to contrast that to conventional building design in which the steps available for hazard mitigation are limited. We can't eliminate the earthquakes; we can't move cities. Abandoning hazardous buildings or retrofitting them is very expensive, and the code provisions for new construction have some expense and are slow in their action.

In contrast, however, lifeline user loss can be influenced and contained by operational decisions. Planning and preparedness really can make a difference in the impact of lifeline damage on the region. Studies of lifelines for damage projection and other research bring such issues to attention and start work on them.

In the same sense, lifeline damage studies should contribute to numerous other environmental exposures. On a small scale, fires, explosions, landslides, and bridge closings resemble the same kind of impact on a system that local earthquake damage would. On a larger scale, floods and storms have the similar potential to cause widespread system damage.

Finally, there's a controlled activity which restricts, say, a transportation system in much the same way that an earthquake would, and that is the repair, reconstruction, and renovation which lies ahead for many older urban areas.

In specific example, Pittsburgh has been the site of a very large roadway reconstruction project, and colleagues of mine undertook a research effort that originated in our earthquake lifeline research and was then directed toward examining safety in operations during this renovation period.

This project was a considerable success. It definitely demonstrated the usefulness of planning efforts for reducing the impact of lifeline system damage.

In conclusion, the overall hazard is not negligible in the East as compared to the West. Lifelines in eastern cities have certain characteristics which may make them relatively more susceptible to damage than their counterparts in the West. They have the further important characteristics of being managed, operated, and used by humans. As a result, planning and preparedness can influence their losses. In my estimation, those studies are also pertinent to lifeline operations in other, more frequent environmental hazard conditions.

Thank you very much.

[The prepared statement of Dr. Oppenheim follows:]

Damage Projection for Future Eastern Earthquakes

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Summary (Identical to Conclusions)

The overall seismic hazard in areas in the eastern United States is not negligible compared to the seismic hazard in the West. Lifelines in eastern cities generally have characteristics of topography and use which may make them more susceptible to damage than their counterparts in the West. As a result, the projected damages may be comparable in magnitude, and are certainly not negligible.

Lifeline systems have the further characteristic of being managed, operated and used by humans. Planning and preparedness therefore can influence the losses should an earthquake occur. Moreover, the key aspects of lifeline behavior are reflected in other, more frequent, environmental conditions such as flood, storm, or rebuilding periods.

Therefore, further studies can contribute to understanding the problem and can yield benefits which extend beyond the narrower question of seismic hazard. We are presently below the optimal level of study. The usefulness of such future studies would be enhanced by integration with activities such as regional disaster planning, utility operations preparedness, and so on.

Introduction

Do future eastern earthquakes present the danger of significant economic and social loss to this nation? Will urban lifeline systems, such as transportation systems, be at risk? Will losses associated with such system performance be sizable? Can we compare those losses to the loss exposure in California, where the seismic risk is more clearly perceived?

More specifically, can we benefit from additional research, investigation, or planning efforts? Will such efforts yield benefits beyond the immediate ones of earthquake hazard mitigation?

In my opinion these questions can be answered with a "yes", qualified by appropriate quantification.

Earthquakes in the Eastern United States

I am an earthquake engineer with further research experience in the performance of systems subject to seismic damage, including the economic evaluation of such system performance. I am familiar with the findings of seismologists regarding earthquake occurrence potential in the eastern U.S., and I feel that certain conclusions are sound and can be taken as established fact. Essentially, eastern earthquakes can be as intense, or¹ large in magnitude, as any occurring in the west. However, they are expected to occur less frequently. Nonetheless, their frequency of recurrence is not negligible, being some portion of that experienced in, say, California. Moreover, it appears that an earthquake in the East will shake a larger area than an earthquake of identical magnitude in the West.

"User Loss" as a Measure of Lifeline Damage

Urban areas are dependent upon a built, engineered infra-structure; those systems have been labelled "lifelines." In this discussion, the transportation system is most often used as a specific example, but the concepts apply generally to all lifelines. Given that earthquake damage occurs, my research studies have employed "user loss" as one measure of the economic consequences to the population of that region. It is defined using the principle of consumer's surplus, or net user benefit. This principle is regularly used to measure the value provided to a region by, say, a new expressway or by improved transit service. We have applied that same principle and take "user loss" as the decrease in those net user benefits for a system damaged by earthquake or by any other phenomena.

Lifelines are distinguished by certain key systems properties, which are indeed

pertinent to the question of damage projection in the East. Those special properties include storage, redundancy, and user preference. Those properties can diminish or eliminate user loss, or they may magnify user loss. Therefore, an accurate understanding of lifeline performance must be prefaced by a discussion of those conditions.

Some lifelines (thought not transportation) contain a quantity of their commodity in storage. For instance, an aqueduct may fail, but at its terminus a several-month supply of water may reside in a reservoir. User losses will therefore not develop if that stored capacity is used. Storage provides a buffer, in time, in which user losses can be avoided while repairs are made.

Redundancy denotes a multiplicity of paths in the network. Some street systems are laid out on a regular rectangular grid, creating a great number of alternate (though perhaps less desirable) paths for users. In contrast, some urban areas must funnel a large number of vehicles through a very few bridges or tunnels. Such bottlenecks represent minimal or nil redundancy for a system. User losses will be magnified when such bottlenecks are involved.

User preference refers to the choice that area residents have in drawing upon the services or commodities supplied by the lifeline system. Users can eliminate many automobile trips if circumstances force them to do so, incurring the loss in value of those foregone trips. However, the pleasure trips are likely less valuable than shopping trips which are in turn less valuable than work trips. The most profound way in which user losses are contained is generally by the good common sense of the individual members of the population. It is important to understand this phenomenon as much as possible, so that local authorities may best manage operations in the wake of an earthquake or other such event. These systems properties are important to understanding total lifeline damage, and to projecting such damage for the eastern United States.

Lifeline Damage for Locations in the East

It is worthwhile to compare western and eastern damage expectations. In a number of ways, lifelines are more susceptible to user loss in the East than in the West for an earthquake of comparable magnitude. Many eastern cities are shaped by rivers and hills, creating true bottleneck conditions in the transportation network. Those same cities may also possess local street systems which are relatively old and hence irregular and narrow. Such systems could display user losses far in excess of

those suffered by a comparable system in the West for the same level of earthquake damage. (Of course, the non-resistant construction employed in the East also lowers the threshold for such damage in the first place.) Moreover, certain such older systems are more heavily used than newer systems, the latter still having some capacity for future growth. As a result, user losses are again potentially magnified for eastern locations relative to western locations.

The specifics of the individual system are important, and evaluations should be made on a case-by-case basis. Nonetheless, the general characterization of eastern cities described above is reasonable in my opinion. As a result, the potential exists for eastern systems to suffer expected losses comparable in magnitude to those for western systems. It would certainly be incorrect to judge that the problem is negligible or truly minor in the East as compared to the West.

The precise level of user loss has not been extensively studied or projected. In studies performed with my colleagues at Carnegie-Mellon University, we have observed user loss to trail the direct damage (that is, repair and replacement) cost in small earthquakes, and then grow to exceed the direct damage cost in large earthquakes. Averaged out, we observed the expected user loss to be comparable in magnitude to the direct damage cost.

The complexity of systems effects often negates quick, first observations, and also places a premium upon effective decision making and management after a disaster. Consider, for instance, municipal water supply. Systems in the West may have multi-month storage reservoirs, or they may have some redundancy in using a mix of surface water sources and groundwater sources. Systems in the East will typically have a limitless source, such as a river or lake, but may have only a few days of storage and only one treatment plant, and hence no redundancy should that plant fail. However, the operators of such systems have an alternative not generally available to operators of systems in the West. They can potentially build an emergency system by taking water directly from the river, giving it crude, bulk treatment, and re-establishing some type of supply. Obviously, the projection of such outcomes requires detailed local study and planning.

Lifeline damage may also present a danger to regional productivity, especially in areas which contain no-growth or retracting industries. In my opinion, deviations from economic theory are often explained by inertia, and disasters often provide the justification to overcome such inertia. To my understanding certain industries chose

to close operations in Johnstown, Pennsylvania, rather than reopen in the aftermath of a storm flood which ravaged the area in the 1970's. On the other hand, the damage incurred in 1964 in Anchorage, Alaska, appears to have led to full rebuilding and expansion. The impact of a natural disaster will be quite different in an area facing a mix of growth and decay trends, as compared to an area enjoying robust growth.

Benefits of Further Study

In my opinion, there are benefits to be gained from further study. The lifeline damage which may occur in eastern locations is a non-negligible component of the seismic risk faced by this nation, and efforts to understand it, project it, and control it should represent some portion of the national effort. I have laid out in this discussion certain things to look for, but the projections have not yet been performed.

Such studies could offer some real benefits, precisely because lifeline systems are managed and used by humans. For conventional structures, the steps available for hazard mitigation are limited. The seismology cannot be altered and cities cannot be moved. Abandonment or retrofitting are very expensive. Enactment of code provisions for new construction is slow, partial, and accompanied by some expense.

Lifeline user loss, however, can be influenced and contained by operational decisions. Planning and preparedness can make a difference. Studies of lifelines, for damage projection, almost invariably bring such issues to attention and therefore start movement toward such maintenance, preparedness, or operating actions.

In this same sense, lifeline damage studies contribute to understanding numerous other environmental exposures. On a small scale, fires, explosions, landslides, or isolated bridge closings damage a system in the same fashion that would an earthquake. Municipalities respond to such perturbations with some frequency. On a larger scale, floods and storms have the potential to cause system damage comparable to earthquakes. Damage aside, evacuation scenarios or strikes can cause a system to display user losses comparable to those representing earthquake lifeline damage. Finally, there also exists a controlled activity which restricts a transportation network in much of the same way that would earthquake damage: the repair, reconstruction and renovation activity that looms large for many urban areas. Pittsburgh has been the site of one of the largest such reconstruction programs, applied to the arterial corridor east of the city. Colleagues of mine undertook a

research effort directed at maintaining safety and network operations during the lengthy repair period. In my estimation, this experience resembled a "laboratory" demonstration of earthquake (massive) damage to the system, and illustrated the effectiveness of such a study.

Conclusions

The overall seismic hazard in areas in the eastern United States is not negligible compared to the seismic hazard in the West. Lifelines in eastern cities generally have characteristics of topography and use which may make them more susceptible to damage than their counterparts in the West. As a result, the projected damages may be comparable in magnitude, and are certainly not negligible.

Lifeline systems have the further characteristic of being managed, operated and used by humans. Planning and preparedness therefore can influence the losses should an earthquake occur. Moreover, the key aspects of lifeline behavior are reflected in other, more frequent, environmental conditions such as flood, storm, or rebuilding periods.

Therefore, further studies can contribute to understanding the problem and can yield benefits which extend beyond the narrower question of seismic hazard. We are presently below the optimal level of study. The usefulness of such future studies would be enhanced by integration with activities such as regional disaster planning, utility operations preparedness, and so on.

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Biographical Sketch

Irving J. Oppenheim is an Associate Professor of Architecture and Civil Engineering at Carnegie-Mellon University in Pittsburgh, where he joined the faculty in 1972. He is a 1968 graduate of The Cooper Union, in New York City, and was awarded an M.S. Degree in 1970 from Lehigh University and a Ph.D. Degree in 1972 from the University of Cambridge. The degrees are in the field of civil engineering.

Dr. Oppenheim has undertaken research and thesis supervision efforts in a number of areas related to earthquake engineering, most notably in lifeline earthquake engineering and in risk analysis. He directed a study sponsored by the National Science Foundation, producing some 19 technical papers and some 12 seminar talks. He chaired a Research Committee within the Technical Council on Lifeline Earthquake Engineering of the American Society of Civil Engineers, and has been an invited expert at meetings held by the Federal Emergency Management Agency, by the Interagency Committee on Seismic Safety, and by the National Science Foundation.

Mr. GORE. Thank you very much.

I think we've heard three excellent statements, and I think they make an excellent contribution to the understanding of these two subcommittees of this very difficult and complex subject.

Our time for questions is necessarily going to be limited, because the hearing has run longer than we anticipated it would, and I want to thank you again for your patience.

Another subcommittee is scheduled to use this room at 1:30, so I'm going to ask only a few questions, and then I'm going to recognize my colleague, the gentleman from Pennsylvania, Mr. Walker; and then I'll ask you if you wouldn't mind responding to some additional questions in writing; they will not be lengthy in nature, but your responses will be included, along with the questions, in the written record of the hearing, if that's acceptable to all of you.

Mr. WALKER. Mr. Chairman.

Mr. GORE. Yes?

Mr. WALKER. I would just prefer you to go ahead and ask the questions. I came in just as a matter of learning. I'm not on either of the two subcommittees. I thank the witnesses for being here. But I want you to make certain you get your questions in because you've—you've prepared on it.

Mr. GORE. Well, I appreciate that. Thank you very much.

I know my colleague has been particularly attentive to the problems associated with earthquake research, because his home district had an event not too long ago, and, quite appropriately, you've devoted a lot of time and study to this.

Dr. O'Rourke, just a few brief questions. If you could tick off some of the low-cost ways of improving earthquake performance in lifeline systems, what would your top priorities be?

Dr. O'ROURKE. I think my top priorities would be increasing the flexibility between certain lifelines and rigid structures. As I showed in some of the slides, there are many connections between tanks, between structures for the walls, and so on, of pump storage buildings and so forth that represent rigid connections, represent areas where there would be a concentration of deformation and distress during earthquake activity, particularly if it's amplified by virtue of permanent ground displacements that would be associated with settlement consolidation of soils and liquefaction.

Oftentimes there are minor modifications needed to allow sufficient flexibility in order to survive the differential displacements that would occur.

Now I have to make that statement also recognizing that there are certain large pipelines, there are certain difficult connections, that do require a bit more expensive modifications, but a lot of modifications could be made in that regard that would help performance very greatly.

I think that there are—another area is learning from some of the vulnerabilities that we have seen, and also understanding some of the strengths that we've seen in the performance of structures, particularly on the west coast, and using those lessons to identify and to reassess what some of the problems might be with regard to future earthquake activity in the East.

In some cases, some of the corrections are fairly straightforward and would result in relatively low cost modification for the systems.

Mr. GORE. Well, very good.

We've taken note of the recommendations made by this panel for additional research into these areas, and taking into account the fact that we don't have all the answers by any means and we need more research in specific areas, Dr. Schiff, bearing that in mind, what would you classify as the most vulnerable parts of power generating plants, and what are the top priority steps you would recommend for increased earthquake resistance there?

Dr. SCHIFF. The plants—you mean power system or just plants?

Mr. GORE. OK; take it that way.

Dr. SCHIFF. Powerplants, as I said, have responded fairly well. Some of the things that can be done to improve probably the earthquake resistance of powerplants is the anchorage of equipment.

What has been proved to be very vulnerable is the ceramic elements in power systems, and—in substations—the high voltage substations, and there's needed research in ways of remedying that; possibly newer materials that are tougher, possibly reconfiguring those systems such that they are inherently more earthquake resistant, reducing the load on the porcelain members, and possibly—there was referred to earlier the base isolation techniques, where you isolate those vulnerable pieces of equipment on rubber mats, so that the earthquake motions do not get to the sensitive equipment.

So there's also a strong need, particularly in the Midwest, for the simple things such as anchorage, at substations, which is a major contributor to failure that we've noticed on the west coast that could be avoided if just good, simple, almost no-cost practices were implemented on new facilities when they're put in. Anchorage of equipment would be probably one of the crucial things there.

Mr. GORE. Very good; thank you.

Dr. Oppenheim, with respect to the newer bridges and highway systems, what specifically would you recommend to increase their earthquake resistance?

Dr. OPPENHEIM. The State of California has undertaken a retrofitting and upgrading of their design criteria for bridges that I think will be very effective at containing seismic damage.

I know that the Federal Highway Administration has directed the generation of a draft document for highway bridge design, and I think it should provide satisfactory levels of performance in the future.

Thank you.

Mr. GORE. Thank you very much, and, again, I want to thank all three of you. We'll have additional questions in writing for the record, but we've exhausted the time that we have this hearing room available for.

You've made a tremendous contribution. I want to thank you and all of the witnesses during today's hearing, and with that we'll stand adjourned.

[Whereupon, at 1:30 p.m., the subcommittees were adjourned.]

APPENDIX I

RECURRENCE RATES AND PROBABILITY ESTIMATES FOR THE NEW MADRID SEISMIC ZONE

by

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ABSTRACT

An updated frequency-magnitude relation for the New Madrid seismic zone is used to derive conditional probabilities for future, large New Madrid earthquakes. We estimate that there is a 40-63% probability of an $m_b \geq 6.0 (M_s \geq 6.3)$ event occurring by the year 2000 and a 86-97% probability by the year 2035. The estimates for a great 1812-type event ($M_s \geq 8.3$) are less than 1% probability by 2000 A.D. and less than 4% by 2035 A.D. These probabilities are contingent on many factors, a number of which remain assumptions because of the lack of a geological or paleoseismological chronology of past New Madrid activity. A conditional probability requires knowledge of a mean recurrence time, the type of distribution, and the standard deviation of actual repeat times about this mean. Four assumed distribution functions - Gaussian, log-normal, Weibull and Poisson - were fit to recurrence estimates based on a combination of historical and instrumental seismicity data. Standard deviation was allowed to vary between one-third and one-half of the mean recurrence time, and a range of conditional probabilities were generated for time intervals of 15 and 50 years from the year 1985. The largest uncertainty in this procedure was the size of the seismicity source area to use for recurrence estimation. Calculations were done for both a large and a small source zone which led to variation in estimated recurrence intervals of a factor of two. The large source zone was favored for the final probability estimates because of the large crustal volume required to elastically store strain energy for great New Madrid earthquakes.

TABLE OF CONTENTS

	PAGE
ABSTRACT	i
INTRODUCTION	1
FREQUENCY-MAGNITUDE RELATION.....	2
Previous Studies.....	3
Current Frequency-Magnitude Relation for New Madrid.....	4
PROBABILITY ESTIMATES.....	8
Terminology and Definitions.....	9
Specific Probability Distributions.....	12
Cumulative and Conditional Probabilities for New Madrid.....	17
DISCUSSION and CONCLUSIONS.....	23
ACKNOWLEDGMENTS.....	28
REFERENCES CITED.....	29

ILLUSTRATIONS

	PAGE
Figure 1. New Madrid seismicity and source zones.....	
2. (a) Frequency-magnitude relation, large source zone....	
(b) Frequency-magnitude relation, small source zone....	
3. Line-fitting comparison.....	
4. (a) Example probability distribution.....	
(b) Illustration of conditional probability.....	
5. Exact and approximate conditional probability.....	
6. New Madrid interevent times and Poisson distribution...	
7. Parameter tree for conditional probability.....	
8. (a) and (b) Illustrative cumulative probabilities.....	
9. (a) Conditional probability, $T_r = 70$ years.....	
(b) Conditional probability, $T_r = 140$ years.....	
(c) Conditional probability, $T_r = 550$ years.....	
(d) Conditional probability, $T_r = 1,100$ years.....	

TABLES

	PAGE
Table 1. Previous frequency-magnitude formula.....	
2. Formula constants and recurrence intervals.....	
3. Weibull constants.....	
4. Worldwide recurrence intervals and standard deviations.	
5. Summary of current cumulative probabilities.....	
6. Summary of current conditional probabilities.....	

INTRODUCTION

Over the past decade remarkable progress has been made in our understanding of the geological, geophysical and tectonic framework of the New Madrid seismic zone. Many aspects of the seismicity, such as spatial dimensions of the active portions of the rift, type and depth of faulting and estimates of source parameters and ground motion are today subject to fairly well defined constraints compared to ten years ago. Such progress has not been matched, however, in the important question of providing accurate estimates of the recurrence times and associated probabilities of large New Madrid earthquakes. In this paper we will review and update the past work on this topic. In addition we will use the derived recurrence rates in combination with some assumed properties of the seismicity to generate probabilistic estimates of future large New Madrid events.

Input data for estimating recurrence intervals are available from three sources: (1) instrumental monitoring; (2) historical seismicity listings; (3) geological and/or tectonic evidence. The applicable time frame for these sources is decades, centuries and the Quaternary Period respectively. Instrumental seismicity is generally the most complete and homogeneous data set, but it suffers the rather severe limitation of sampling only a small fraction of the repeat time of large events. Historical seismicity may span one or more recurrence intervals of major quakes (in some cases) but is usually a more suspect data set because of lack of completeness and rather large uncertainties in magnitude assignment and epicentral location. Where recoverable, slip rates on Quaternary faults have been incorporated into seismic hazard analysis to good effect, e.g., the Wasatch Front (Ryall and Smith, and following papers, 1980) and intraplate Japan (Wesnousky et al., 1982; 1983). The ratio of seismic to aseismic movement for these faults is generally unk-

nown and this introduces an uncertainty in this technique.

More recent geological information may be gained by analyzing deformation preserved in sediments over and along fault zones as has been done in southern California (Sieh, 1978; Raleigh et al., 1982) and New Madrid (Russ, 1979). Such estimates are subject to their own set of uncertainties such as the difficulty of establishing reliable dates of the deformational episodes and of determining magnitudes of the causative events.

No first-hand fault slip information is available for the New Madrid seismic zone because of the thick cover of alluvium. Moreover, no chronology of past large slip events exists, although the conclusion of Russ (1979) that three such events occurred in a maximum interval of 2,250 years provides a general and important constraint. Therefore in this paper we must rely solely on instrumental and historical seismicity data for the estimation of New Madrid recurrence intervals. As will be shown in a later section, such information is not adequate to confidently assign probabilities to these recurrence values. In the absence of measured values of such necessary quantities as strain rate or the distribution of actual recurrence times about the estimated mean return periods, plausible values are taken from theoretical studies or from literature on other fault zones and used to construct rough estimates of the conditional probability of large New Madrid earthquakes. These are the first published conditional probabilities for the New Madrid zone. We hope they will serve as a reference frame that can be refined and improved as additional data become available.

FREQUENCY-MAGNITUDE RELATION

The magnitude distribution of earthquake occurrences is generally

observed to follow the Gutenberg-Richter relationship

$$\log(N_c) = a - bM \quad (1)$$

where N_c is the number of events greater than or equal to magnitude M , and a and b are constants. Applied over a given time period, the number of earthquakes in a given magnitude range is obtained, yielding a characteristic recurrence time for that magnitude, based on the assumption that the process is stochastic (i.e., that the occurrence rate is not a function of time). The constant a , the activity parameter, provides a measure of the overall occurrence rate of earthquakes in the zone considered and is the zero magnitude intercept on a semilog plot. The constant b , or b -value, is controlled by the distribution of events between the higher and lower magnitude ranges. Both constants influence derived recurrence times; therefore it is essential that the values and the variance of these constants be determined as accurately as possible.

PREVIOUS STUDIES

Early efforts at obtaining a recurrence relation for the New Madrid region used historical compilations and Modified Mercalli intensities rather than magnitudes (McClain and Myers, 1970; Algermissen, 1972; Mann et al., 1974). The average return periods for large earthquakes ($MMI_0 \geq X$) as determined by these studies varied between 175 and 700 years (Nuttli, 1974).

Table 1 provides a summary of previous New Madrid recurrence formulas based on magnitude. These results are not directly comparable because of differences in magnitude, area normalization, cumulative versus non-cumulative number of events and varying time windows. They do, however, provide an indi-

cation of general recurrence ranges developed by a variety of workers using a variety of approaches and boundary conditions. These data imply that a destructive New Madrid earthquake ($m_b 6.0$) can be expected on the order of every 50-100 years, a great earthquake ($m_b 7.0/M_s 8.3$) every 300-1000 years and a maximum magnitude event ($m_b 7.3/M_s 8.8$) every 500-1500 years. This assumes that New Madrid behaves in a time-predictable manner as has been demonstrated for both interplate (Bufe et al., 1977) and intraplate (Shimazaki and Nakata, 1980) fault zones. Since a prehistoric chronology is not available for New Madrid we cannot verify such behavior; it remains the fundamental assumption of this paper.

A CURRENT FREQUENCY MAGNITUDE RELATION FOR NEW MADRID

Data Base. The historical seismicity listing compiled by Nuttli and Brill (1981) was combined with the instrumental record of the St. Louis University seismic network (Stauder and others, 1974-1983) to estimate mean recurrence rates for the New Madrid seismic zone. Two different source zones were used in this study (Figure 1), an approach taken in response to the work of Wesnousky and Scholz (1983). Based on Quaternary fault slip rates in intraplate Japan, they suggested that the observed logarithmic distribution of earthquake magnitude is a consequence of a logarithmic distribution of individual fault dimensions rather than a distribution of earthquake size on a single fault. Thus, it is not critical (or even advisable) to restrict the source zone to only the most active portion of New Madrid, even though it is probable that major earthquakes could only occur there. The smaller source zone is about one-fifth the size of the larger zone, yet contains 60% of the

historical data and 76% of the instrumental data. It is represented by the small rectangle of Figure 1. Table 2 lists the parameters for each source zone. Arguments favoring selection of the larger source zone for New Madrid recurrence rates are presented in the final section.

A cumulative frequency-magnitude plot of the combined historical and instrumental data sets for both source zones is shown in Figure 2; it was generated following the technique outlined in Johnston (1981). From the instrumental data set, nine years of data were available, ranging from a completeness threshold magnitude of 1.7 to a maximum of 5.0. This was combined with the historical listing, 158 years of data, ranging ^{from} a threshold magnitude of 3.6 to a maximum of 6.2. In order to combine the data sets, each set was normalized to cumulative events per year.

The transition from instrumental to historical data was made between magnitude 3.5 and 3.6. This assured a near completeness of both data sets, as reporting of low magnitude in Nuttli and Brill is complete to M3.6 (Johnston, 1981), and magnitudes above 3.5 for which nine years may not be an adequate sampling time are excluded from the instrumental portion of the plot.

Methodology. Both linear regression and maximum likelihood techniques were used to determine the Gutenberg-Richter constants a and b for the "best-fit" line through the data. Each technique has advantages and disadvantages that have been extensively discussed in the literature (e.g., Weichert, 1980; Bender, 1983). As pointed out by Weichert, conventional least squares (LS) is the maximum likelihood method for independent data with a Gaussian error distribution. For cumulative frequency-magnitude plots as used in this study, these conditions are obviously violated.

Conceptually maximum likelihood (ML) is the superior estimation technique; in practice, however, ML accords so little weight to the upper

magnitude points, that it is less suitable than least squares for estimating the recurrence intervals of high magnitude, infrequent earthquakes (See Shi and Bolt [1982] for a discussion.) This is especially true for large data sets such as used in this study. For large, well defined data sets, then, cumulative least squares provides a reliable estimation of the data (c.f., Weichert, 1980).

Because of the arguments of the foregoing paragraph and because of the rather *ad hoc* manner in which the constant *a* is determined by ML (most authors constrain the line slope *b* through either the minimum or the average magnitude data point), we chose to base our derived frequency-magnitude formula on least-squares regression. Table 2 contains the constants *a* and *b* of equation (1) and their uncertainties computed by both LS and ML for magnitude increments of 0.1 and 0.5 for both the large and small source zone.

Statistical uncertainties were computed as follows. For *a*, with *n* magnitude intervals, x_i = *i*th magnitude interval and $y_i = (\log N_i)$,

$$\sigma_a = \frac{\sqrt{\sum_{i=1}^n [y_i - (a - by_i)]^2 / n - 2}}{\sqrt{\sum_{i=1}^n x_i^2 - \left(\frac{\sum_{i=1}^n x_i}{n}\right)^2}} \cdot \sqrt{\frac{\sum_{i=1}^n x_i^2}{n}} \quad (2)$$

(e.g., Miller, 1982). For *b*, the standard error of *b* for a large number of events from Shi and Bolt (1982) is used:

$$\sigma_b = 2.30 b^2 \sqrt{\frac{\sum_{i=1}^n (M_i - \bar{M})^2}{n(n-1)}} \quad (3)$$

where $\bar{M}$ is the mean magnitude corrected for grouped magnitudes following Bender (1983).

Also included in Table 2 are mean recurrence intervals T_r of 70 and 140 years for $m_b \geq 6.0$, and 550 and 1,100 years for $m_b \geq 7.0$. These are the values of T_r to be used in the subsequent probability analysis, and are intermediate to values determined by LS for $\Delta M = 0.1$ and 0.5. ML recurrence values are included in Table 2 for reference but are not used for probability estimation.

A frequency-magnitude relation for New Madrid derived from the least-squares analysis and from the intermediate recurrence times of Table 2 is:

$$\log(N_C) = 3.43 - 0.88 (m_b) \quad [\text{Large source zone}] \quad (4a)$$

$$\log(N_C) = 3.32 - 0.91 (m_b) \quad [\text{small source zone}] \quad (4b)$$

with $\sigma_a = 0.070$ and $\sigma_b = 0.040$.

PROBABILITY ESTIMATES

A problem of increasing concern in the Central United States is the likelihood of occurrence of the next large New Madrid earthquake. (This is a separate and simpler question than that of finding the total seismic hazard which entails estimating the level of ground motion generated by multiple source zones and the chance of exceeding it at a given location.) In this section we will examine how well probabilities of occurrence can be estimated for the New Madrid seismic zone.

The average return period or recurrence interval, as previously derived, does not in and of itself supply sufficient information to determine probability of occurrence. It is also necessary to know the frequency distribution of recurrence intervals for a given magnitude or magnitude range. That is, for a time span much greater than the estimated recurrence time, what is the distribution of actual repeat times about the estimated mean? Given the mean, the type of distribution and the standard deviation of the observations, either cumulative probability, (the probability that an earthquake would already have happened) or future (conditional) probability may be ascertained.

For the New Madrid seismic zone, neither the type of distribution of recurrence intervals, nor their standard deviation from the mean is known. Because of this lack of necessary information we can only proceed by assuming New Madrid behaves in certain ways. Our approach is to take a range of assumed distributions and standard deviations and examine the effect of these assumptions on probabilistic estimates. If the final estimates do not diverge too much, we can have confidence that the determined probabilities are fairly stable or robust, i.e., insensitive to the statistical assumptions. This presumes, of course, that our assumptions are comprehensive enough to encom-

pass the actual behavior of the New Madrid seismic zone.

Terminology and Definitions

Before examining individual cases we define some frequently used terms and concepts.

(1) The statement "x has the probability $P(x)$ " means that if an operation (read 'earthquake occurrence') is repeated a great number of times, it is practically certain that the relative frequency of x is equal to $P(x)$. Here relative frequency is just the number (range) of actual outcomes divided by the number (range) of possible outcomes.

(2) Cumulative Probability Distribution. If X is a random continuous variable that is a property of events of a population, then for any real number x the distribution of X, denoted $F(x)$, is defined as the number (range) of all events with $X \leq x$ divided by the total number (range) of events. Therefore $F(x)$ also gives the probability of choosing at random an event with $X \leq x$. Thus

$$F(x) = P(X \leq x).$$

$F(x)$ is the cumulative probability distribution (or distribution function) for an arbitrary distribution F and arbitrary variable x. In this study we are interested in variations with time t and assign specific cumulative distributions as follows: Gaussian (or normal), $G(t)$; log-normal, $L(t)$; Weibull, $W(t)$; Poisson, $S(t)$, (to avoid confusion with cumulative probability, $P(t)$).

(3) Probability density. If x is a continuous variable then there exists a function f such that

$$F(x) = \int_{-\infty}^x f(x) dx \quad . \quad (5)$$

$f(x)$ is called the probability density; it is just the derivative of the cumulative distribution function, i.e.,

$$F'(x) = f(x) \quad (6)$$

Note that since $F(x) = P(X \leq x)$, if events in the sample space are mutually exclusive and collectively exhaustive, it follows that

$$P(x) = \int_{-\infty}^{+\infty} f(x) dx = 1 \quad (7)$$

and

$$P(a \leq x \leq b) = F(b) - F(a) = \int_a^b f(x) dx$$

Specific probability densities in this paper are denoted as follows: Gaussian, $g(t)$; log-normal, $l(t)$; Weibull, $w(t)$; Poisson, $s(t)$.

(4) Conditional probability. Let A and B be two events (or two sets of outcomes) in a sample space. Conditional probability is defined as the probability of event B occurring given that event A has already occurred. It is denoted by $P_c = P(B|A)$. Thus P_c is just the ratio

$$P_c = P(B|A) = \frac{P(A \cap B)}{P(A)}$$

where $P(A \cap B)$ is the intersection of A and B, that is, a subset of sample space consisting of all possible outcomes contained in both A and B. In the context of earthquake recurrence, A and B are events in the same magnitude range and

$$P_c = \text{Prob.} \left[\text{Next event (B) within } (t, t + \Delta t) \mid \text{Preceding event (A) at } t_0 \right]$$

A useful formulation of conditional probability is in terms of cumulative probability or area beneath the curve of a probability density function. This is illustrated in Figure 4 for an arbitrary distribution $F(t)$. P_c is the ratio of two areas: one area beneath $f(t)$ between t and $t+\Delta t$ representing the probability of occurrence during this time interval; the other is the area beneath $f(t)$ from t to $+\infty$ representing the probability that the event will eventually occur given that at time t it has not yet happened. Thus

$$P_c = \frac{\int_t^{t+\Delta t} f(\tau) d\tau}{\int_t^{\infty} f(\tau) d\tau}, \quad (8)$$

or from equations (5) and (7)

$$P_c = \frac{F(t+\Delta t) - F(t)}{1 - F(t)} = \frac{\Delta F}{1 - F(t)}. \quad (9)$$

Frequently the computation of P_c is simplified by using $F'(x) = f(x)$ (from equation 6) and expanding $F(x)$ in an incremental Taylor series:

$$\Delta F = F(x+\Delta x) - F(x) = \Delta x F'(x) + \frac{\Delta x^2}{2!} f''(x) + \dots \quad (10)$$

Thus, for example, for a Gaussian conditional probability, a first-order approximation is

$$P_c = \frac{\Delta G}{1 - G(t)} = \frac{\Delta t g(t)}{1 - G(t)}. \quad (11)$$

Care must be taken, however, to apply this approximation only for $\Delta t \ll t$; otherwise unreasonably large conditional probabilities will be obtained (in extreme cases P_c will exceed 1). Figure 5 illustrates the difference between computing an approximate P_c from equation (11) and an exact P_c from equation (9).

Specific Probability Distributions

Four possible probability distributions were considered as representations of the actual recurrence interval distribution of New Madrid earthquakes for a given magnitude range. Each distribution has seen previous use in seismic hazard analysis. In the absence of an actual New Madrid chronology, we feel that this approach has a high likelihood of bracketing the actual behavior of the New Madrid seismic zone.

Poisson

The discrete Poisson distribution has the property that the probability of occurrence of an event is exactly the same for a given time interval anywhere along the time axis. This time-stationarity property is usually expressed in a distribution function for the number of events per unit time. More useful for our purposes is the distribution of interevent times which may be shown to follow a negative exponential distribution for a Poisson process (Lomnitz, 1974):

$$s(t) = \frac{1}{T_i} e^{-t/T_i} \quad , \quad (12)$$

where T_i is the average interevent time. Figure 6 shows the distribution of instrumental New Madrid seismicity and the Poisson probability density function for $T_i = 2.04$ days.

Poisson statistics have been used extensively to represent time sequences of earthquakes. In many cases seismic zones seem to closely emulate a Poisson process (e.g., Fig. 6). However, this is a different property from the one of interest here, which is the distribution of occurrence times about an average recurrence time for a given magnitude range. For this, Poisson probabilities are not an adequate representation because the independence of Poisson events results in a constant conditional probability rather than one increasing in time since the last event as required by the time-predictable model assumed for New Madrid.

Even though Poisson probabilities are not appropriate for this study, their extensive use in the seismic hazard literature make them useful as a reference level when time-dependent conditional probability is discussed.

The cumulative Poisson probability when T_r is the average recurrence time is:

$$S(T \leq t) = \int_0^t s(\tau) d\tau = 1 - e^{-t/T_r} \quad (13)$$

Substitution in equation (9) yields a conditional probability:

$$S_c(t, \Delta t) = 1 - e^{-\Delta t/T_r} \quad (14)$$

where Δt is the interval under consideration for an earthquake reoccurrence.

Note that for a given Δt , S_c is constant and does not depend on t , the elapsed time since the last event.

Gaussian

The Gaussian (or normal) probability density function is given by

$$g(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{t-T_r}{\sigma} \right)^2 \right] , \quad (15)$$

where σ is the standard deviation and T_r is the mean repeat or recurrence time. The cumulative probability is

$$G(T \leq t) = \int_{-\infty}^t g(\tau) d\tau . \quad (16)$$

This integral cannot be evaluated by standard techniques, but extensive tables of values are available when $G(T \leq t)$ is transformed into a standardized normal distribution using

$$z = \frac{t-T_r}{\sigma} . \quad (17)$$

From equations (9) and (26) the Gaussian conditional probability is

$$G_c(t, \Delta t) + G_c(z, \Delta z) = \frac{G(z+\Delta z) - G(z)}{1 - G(z)} . \quad (18)$$

Values for $G(z+\Delta z)$ and $G(z)$ were taken from Tables of Normal Probability Functions (National Bureau of Standards, 1953) for this report.

The Gaussian distribution has recently been used by a number of authors to estimate conditional probabilities of seismic zones in Japan and the United States (Wesnousky et al., 1984; Sykes and Nishenko, 1984; Jacob, 1984). In these studies either long historical chronologies, geological slip rates or paleoseismic data were available to place constraints on either the estimates of mean recurrence time or the appropriate distribution to apply. Gaussian conditional probabilities will be an important component of this paper, but we emphasize that no independent evidence exists that favors its use for New Madrid.

Log-Normal

The log-normal distribution has found frequent application in the earth sciences (e.g., Till, 1974) and in at least one case has been applied to earthquake recurrence times. Jacob (1984) compared the fit of the interoccurrence intervals of large ($M_S \geq 7.8$) Aleutian earthquakes to both Gaussian and log-normal distributions and considered the log-normal to be the more appropriate representation. It is included in this study as a potentially valid distribution for New Madrid recurrence times.

The log-normal distribution can be generated from the Gaussian (or vice-versa) by the variable transform $t = \ln(t)$, where $\ln$ is the natural (base e) logarithm. A log-normal density function $l(z)$ is obtained from the standardized normal distribution using the following relations:

$$Z = \frac{\ln(t) - T_r^*}{\sigma^*} \quad ; \quad \sigma^* = \sqrt{\ln \left(\frac{\sigma^2 + T_r^2}{T_r^2} \right)} \quad (19)$$

$$T_r^* = \ln(T_r) - \frac{\sigma^{*2}}{2}$$

where T_r^* and σ^* are the mean and standard deviation of the log-normal distribution.

Weibull

The Weibull distribution was originally developed by Weibull (1951) on a purely empirical basis for application to instances of failure of individual components of large systems. Hagiwara (1974) and Rikitake (1975) applied this distribution to data on crustal strain preceding large earthquakes. If the strain rate is approximately constant (as required by the time-predictable model) a Weibull distribution of "ultimate strain" will allow estimates of probability of occurrence. Since this Japanese work, Weibull statistics have been increasingly applied in seismic hazard research (e.g., Brillinger, 1982; Kiremidjian and Anagnos, 1984; Nishenko, 1984).

The Weibull probability density function is given by

$$w(t) = \lambda v t^{v-1} e^{-\lambda t^v}, \quad (20)$$

where λ and v are constants that are related to T_r , the mean time to failure and to σ , the standard deviation, as follows (Hagiwara, 1974):

$$T_r = \int_0^\infty t w(t) dt = \lambda^{-1/v} \Gamma\left(\frac{v+1}{v}\right) \quad (21)$$

$$\frac{\sigma}{T_r} = \sqrt{\Gamma\left(\frac{v+2}{v}\right) - \Gamma^2\left(\frac{v+1}{v}\right)} / \Gamma\left(\frac{v+1}{v}\right), \quad (22)$$

where Γ is the gamma function. ν is often referred to as the shape parameter and increases as σ decreases. λ is exponentially related to the mean rate of failure and increases as T_f decreases. Table 3 lists the Weibull parameters computed for this study from equations (21) and (22) as well as some found in the literature.

Equation (20) may be directly integrated to obtain the cumulative Weibull probability:

$$W(T \leq t) = \int_0^t w(\tau) d\tau = 1 - e^{-\lambda t^\nu}, \quad (23)$$

which yields a conditional Weibull probability of

$$W_c(t, \Delta t) = \frac{\exp[-\lambda t^\nu] - \exp[-\lambda(t+\Delta t)^\nu]}{\exp[-\lambda t^\nu]} \quad (24)$$

We note that the Weibull hazard rate, defined as $dW(t)/dt = \lambda \nu t^{\nu-1}$ is often used as a conditional probability (e.g., Kiremidjian and Anagnos, 1984; Hagiwara, 1974). This expression is just a first-order Taylor expansion and can lead to significant overestimates of $W_c(t, \Delta t)$ in the same manner as shown for the Gaussian distribution (Fig. 5).

Cumulative and Conditional Probabilities for New Madrid

In this section we present probability estimates for large ($m_b \geq 6.0$) and great ($m_b \geq 7.0/M_s \geq 8.3$) New Madrid earthquakes based on the information presented in the preceding sections.

Cumulative and conditional probability estimates require choice of a pro-

bability distribution, specification of the distribution mean, and specification of the standard deviation of observations about the mean. Conditional probabilities also require the length of the future time interval, Δt . Figure 7 is a parameter tree depiction of the various parameter combinations that were chosen for analysis and illustration. The choices were dictated by a variety of factors as discussed below.

Magnitude. We restrict our data presentation to two magnitudes: an $m_b 6.0(M_s 6.3)$ event which could be locally destructive over one or more counties and $m_b 7.0(M_s 8.3)$ which we take as a great 1812 - type New Madrid event. A maximum magnitude quake ($m_b 7.3/M_s 8.9$ [Nuttli, 1983]) has such low cumulative and conditional probabilities as to be of little interest for this paper.

Average Recurrence Interval. In the absence of any geological or paleoseismological information, this parameter is taken directly from the frequency-magnitude analysis of the first part of this paper. As is evident from Table 2 recurrence estimates for a given magnitude range have a large range. Dimensions of the source area and the line-fitting technique are the two principal sources of this variability. Differences in the size of the chosen source zone cause differences of roughly 100% in the estimates of mean recurrence times, and different line-fitting methods yield variations on the order of 50%.

Such a large range of estimated repeat times must be considered in any realistic probabilistic analysis. Our approach was to take a value from the low and from the high end of the range of estimates of T_r for use in the probability analysis, and thereby bracket the actual behavior of New Madrid. Extreme points were not selected because this would smear the results beyond usefulness and because extremes are accounted for to a degree by selecting a

range of standard deviations about the estimated mean (see next section). Thus in Figure 7, a range of 70-140 years is used for T_r ($m_b 6.0$) and 550-1,100 years for T_r ($m_b 7.0$).

Standard Deviation. Frequency-magnitude analysis yields an estimated recurrence time T_r but no estimate of the variation of T_r as the seismic zone proceeds through many seismicity cycles. This variability is physically real (as opposed to the variability induced by methodology as discussed in the last section) and is exhibited by virtually all seismic zones that have been identified as behaving in a cyclic manner. Table 4 presents a representative (but not exhaustive) listing of repeat times and standard deviations that have been reported in the literature for various seismic zones worldwide.

Information such as that in Table 4 is not available for New Madrid; therefore standard deviation must be an assumed parameter. Using Table 4 as a guide, the standard deviation σ is allowed to vary from one-third (33%) to two-thirds (67%) of T_r (Fig. 7). For σ in excess of $.5T_r$ the very concept of the time-predictable seismicity model loses its usefulness. The observed variability of the repeat times of magnitude 5 and 6 quakes in the historical record suggests σ should not be smaller than one-third of T_r .

Type of Distribution. Type of distribution is another assumed parameter for New Madrid. As previously discussed we selected four commonly used distributions for analysis. One of them, the Poisson, is included only for reference as it is not applicable to a time-predictable model.

For New Madrid earthquakes of body-wave magnitude 6.0 and above, the elapsed time since the last event(s) is still less than the estimated repeat time (with the exception of $T_r = 70$ years). The analysis of this section will show that for such a time frame, choice of probability distribution makes little difference in computed probabilities. Sykes and Nishenko (1984) reach a

similar conclusion for several California fault systems.

Time Interval, Δt . The choice of a time interval for computing conditional probabilities is completely arbitrary since the exact form (equation 9) of P_c rather than the first-order Taylor series approximation (equation 11) is employed in this study. We selected a Δt of 15 years to coincide with a probability of occurrence by the turn of the century and a Δt of 50 years as representative of the probability of occurrence during a lifetime.

Cumulative Probability

It is of greater interest to know the probability of a large earthquake happening during some future time interval than to know the probability that it would have already happened by now (the present). For this reason we emphasize conditional rather than cumulative probabilities. We do include, however, the general behavior patterns of cumulative probability for the four distributions considered in this study. These are illustrated in Figure 8 and summarized in Table 5.

In Figure 8(a) cumulative probabilities are shown for an $m_p \geq 6.0$ quake with a mean recurrence interval from the extreme upper-end of its range ($T_r = 140$ yrs). Gaussian and Weibull values are within 1% and vary from the log-normal by a maximum of 5%. Poisson values are significantly higher than the other distributions for $t < T_r$ and lower for $t > T_r$. This behavior holds for all choices of T_r and σ and carries over into the conditional probability estimates.

Figure 8(b) illustrates the dependence of cumulative probability on T_r and σ for an $m_p \geq 7.0$ earthquake. For the range of recurrence intervals and standard deviation considered in this study, cumulative probability can vary up to ~60% with T_r and ~10% with σ . Only the Gaussian and Poisson cases are

shown since Weibull and log-normal differences from Gaussian are <10% (Poisson is shown for reference only). Thus the estimate of T_r has much the greater effect on calculated cumulative (and conditional) probability; choice of σ and choice of distribution provide a modulation of only about 10%.

Table 5 summarizes cumulative probabilities for New Madrid for the year 1985. For the large source area of Figure 1 ($T_r=70$ and 550 yr) the probability that an $m_b \geq 6.0$ quake would have occurred between 1895 (the last $m_b > 6.0$ event, Charleston, MO) and 1985 has reached 72-83%. Similarly for $m_b \geq 7.0$ since 1812, $P(t=1985)$ is only 0.3-8.5%. If recurrence intervals derived for the small source zone are considered ($T_r=140$ and 1100 yr), the computed values fall to 11.5-26.4% and <<1.0-4.6%. In all but the case for $T_r=70$ yr and the elapsed time $t=90$ yr, Poisson statistics significantly overestimate the likelihood of occurrence.

Conditional Probability

Conditional probabilities for large New Madrid earthquakes for the next 15 and the next 50 years are presented in this section. Choice of values for the parameters which affect the calculations -- type of distribution, mean recurrence time and standard deviation -- have been previously discussed and are summarized in Figure 7.

The data are presented in a series of four figures (Fig. 9 a,b,c,d) each depicting conditional probabilities (P_c) for Gaussian, Weibull, log-normal and Poisson (reference only) distributions. Figure 9(a) and (b) are for an $m_b \geq 6.0$ earthquake with T_r ranging from 70 to 140 yrs; Fig. 9(c) and (d) are for an $m_b \geq 7.0$ event with T_r equal to 550 or 1,100 years. The plots have been carried out to elapsed time roughly twice T_r so that the asymptotic behavior of P_c at large t would be shown. Three reference times, t_0 , T_r , and $t=1985$, are shown

on each graph. Shaded regions indicate the range of P_C for a given Δt as the standard deviation varies from one-third to one-half of T_r .

There are several important features in Figure 9 to which we call attention.

(1) In all cases the present (year 1985) is less than $1.5T_r$. In this time range, the choice of probability distribution makes little difference in P_C . This is particularly true for the Weibull and Gaussian cases; log-normal yields the lowest P_C for times close to Δt and rises most steeply as t approaches T_r .

(2) Allowing σ to range from $.33T_r$ to $.50T_r$ has a greater effect on conditional than on cumulative probability but only for $t > T_r$, times generally beyond our concern in this study. For times less than roughly one-half T_r an increase in σ increases P_C because area beneath the probability density function is shifted from the distribution mean (T_r) to the tails. However, for $t > T_r$, P_C for $\sigma = .50T_r$ is always less than P_C for $\sigma = .33T_r$.

(3) For elapsed time $t > 2T_r$ the log-normal distribution yields significantly lower estimates of P_C than either the Weibull or Gaussian. This case appears to apply to the conditional probabilities for some of the Aleutian Arc segments computed by Jacob (1984).

(4) The constant Poisson conditional probabilities will yield estimates that are consistent with the other distributions only over a very restricted range of elapsed times and should not be used for conditional probability estimation for a time-predictable model of seismicity. In contrast, Poisson cumulative probabilities are consistently high for $t < T_r$ and may be used to provide a conservative (i.e., upper bound) estimate of seismic hazard.

Fifteen- and 50-year conditional probability estimates for the year 1985 are compiled in Table 6. The likelihood of a great ($M_0 \geq 7.0/M_S \geq 8.3$) New Madrid

earthquake in the next 15 or 50 years is uniformly low, reaching a maximum of 4.7% for a Weibull distribution with $T_r=550$ yr, $\sigma=.5T_r$, $\Delta t=50$ yr. Log-normal estimates are very low, often much less than 1%.

P_c estimates for an $m_b \geq 6.0$ event exhibit a wide variation, ranging from 9 to 67% for $\Delta t=15$ yr and from 34-99% for $\Delta t=50$ yr. About 10% of this variability arises from type of distribution (Poisson excluded), 10-25% from choice of σ , and from 25 to 50% from choice of $T_r=70$ or 140yr. In the 'restricted range' column of Table 6 we give a preferred probability range taken from the low, $T_r=70$ yr recurrence time (the large source area of Figure 1). Arguments supporting this choice are presented in the concluding section.

DISCUSSION AND CONCLUSIONS

The probability estimates of this report rely on the assumption that the New Madrid seismic zone generates major earthquakes in a repeated fashion. It is further assumed that the occurrence of large events is periodic rather than episodic, a distinction we make on the basis of the standard deviation of repeat times about the mean recurrence interval. If σ is greater than 50% of the mean recurrence time, we term the activity episodic and our probability estimates do not apply. If σ is less than 50% the calculated probabilities reported here should be reasonable estimates of the likelihood of future large New Madrid earthquakes.

The 15-and 50-year conditional probabilities listed in Table 6 have a very wide range, e.g., from 9% to 67% for $m_b \geq 6.0$, $\Delta t=15$ yr, and from 34% to 99% for $\Delta t=50$ yr. Most of the variability arises from the choice of source zone boundaries for the seismicity data set. We favor the choice of the

larger source zone (which leads to shorter recurrence times and consequently higher probabilities) and offer the following argument in support of this selection.

The Large Source Zone. According to Nuttli's most recent estimates the three great New Madrid earthquakes of the winter of 1811-12 had surface-wave magnitudes of 8.5, 8.4 and 8.8 (Nuttli, 1983). Even if we neglect the extensive aftershock sequences, these great events represent a strain energy release of $\sim 1.6 \times 10^{25}$ ergs. The question we pose is, what crustal volume is required to store this strain energy as elastic potential energy?

If we consider the simplest case where strain is represented by a single component of shear (ϵ), then strain energy per unit volume (e) is

$$e = \frac{1}{2} \mu \epsilon^2 \quad ,$$

where μ is the rigidity modulus. Taking $\mu = 5 \times 10^{11}$ dyn cm $^{-2}$ and using Rikitake's (1981) most recent estimate of ultimate crustal strain, $\epsilon_{\max} = 4.4(\pm 1.7) \times 10^{-5}$, we obtain

$$e = 182-930 \text{ ergs/cm}^3 \quad .$$

That is, typical crustal rock cannot store more than 182 to 930 ergs/cm ^{3} elastically without brittle failure. The 1811-12 events would have required a crustal volume of $1.7-8.8 \times 10^{22}$ cm ^{3} to store the energy released as seismic radiation.

What portion of the crust is elastic? Central U.S. earthquakes occur to depths of 20-25 km. Recently some authors have argued that the crust contains

a ductile shear zone at depths of ~ 20 to ~ 40 km in which ductile deformation (on the order of mm/yr) strains the overlying brittle crust (e.g., Zoback et al., 1984). We take 25 km as a (possibly high) estimate of the thickness of the elastic crust. This yields an area of 680,000 to 3,500,000 km² required for strain energy storage.

The areas of the large and small source zones of Figure 1 are 157,700 km² and 29,960 km² respectively. The required crustal area for strain energy accumulation for great New Madrid quakes far exceeds the small source zone: it is for this reason that we favor the larger zone. Increasing the depth of the ductile-brittle transition to 40 km or assuming values for μ above the already high value taken would not change these conclusions. If an older, higher estimate of ultimate strain is taken, $\epsilon_{\max} \sim 1.5 \times 10^{-4}$ (Tsuboi, 1956), then strain energy density increases to 5,625 ergs/cm³ and the required crustal area to store the prior strain is 138,000 km² (for 25 km depth), still on the order of the dimensions of the large source zone.

By making this order-of-magnitude calculation for the accumulation volume of prior strain, we are not proposing that a great earthquake could occur anywhere in the large source zone of Figure 1. We believe that such an event could only occur in the region within the small source zone. However, the strain storage limitations of the brittle crust require the participation of crustal rock significantly beyond the limits of the small source zone. This would, of necessity, encompass the fault population of the large source zone; hence the large zone is the proper one for recurrence estimation.

Are the mean recurrence times of large events estimated from the large source zone compatible with other lines of evidence? From Table 2, an $m_{\max} \geq 6.0$ event is expected every 55-88 yrs on average (compared to 124-155 yrs for the

smaller zone). Since 1812 two $m_b \geq 6.0$ events have occurred: in 1843 near Marked Tree, AR and in 1895 near Charleston, MO. The average interevent time is 52 yrs; if the dates 1812 and 1985 are used to bracket these events an average recurrence of $58(\pm 30)$ years is obtained. These sparse data are certainly more compatible with the large source zone recurrence estimates than with those of the small zone.

Another order-of-magnitude check can be made from the displacement values that Nuttli (1983) estimates for the great New Madrid quakes. According to Nuttli such events have displacements of 5-8 meters. If a representative source dimension is ~ 100 km, this represents a strain of $5-8 \times 10^{-5}$ which is close to the ultimate strain estimate of Rikitake. A repeat time of 550 yrs requires a strain rate of $\dot{\epsilon} \sim 1-1.5 \times 10^{-7}$ /yr, a high but not unprecedented value. Harada (1978) found for the south Kanto district of intraplate Japan a rate of 1×10^{-7} /yr over a 70-year period. Normal strain rates for active interplate zones are at least an order of magnitude larger.

Our overall conclusion can be stated as follows. Recurrence rates derived from the large source zone of Figure 1 are preferred to those of the small source zone because of the large volume of crustal rock required to store the strain potential energy of great New Madrid earthquakes. The recurrence rates are compatible with the occurrence of $m_b \geq 6.0$ events in the historical record, with displacement estimates for great events, with estimates of ultimate crustal strain, and with intraplate strain rates in Japan. The location of a lower magnitude 6 event would not be restricted to the small source area whereas an $m \sim 7-8$ event is considered possible only on the principal fault segments of the New Madrid zone.

Restricted Probability Range. In Table 6 we have included a restricted range of conditional probabilities; these values are based on the arguments

of the previous discussion in favor of large source zone recurrence intervals, i.e., $T_r=70\text{yr}$ for $m_b \geq 6.0$ and $T_r=550\text{yr}$ for $m_b \geq 7.0$. Our restricted range estimates are simply an average of the range of values obtained with the Gaussian, log-normal, and Weibull distributions and are repeated here as one of the main conclusions of this study.

	<u>Aver. Repeat time</u>	<u>Probability by Year 2000 A.D.</u>	<u>Probability by Year 2035 A.D.</u>
$m_b \geq 6.0 (M_s \geq 6.3)$	70 yr ($\pm 15\text{yr}$)	40-63%	86-97%
$m_b \geq 7.0 (M_s \geq 8.3)$	550 yr ($\pm 125\text{yr}$)	0.3-1.0%	2.7-4.0%

These probability estimates would be much lower if the small source zone were appropriate: for $m_b \geq 6.0$, $\sim 10\%$ by 2000 A.D., and $\sim 39-45\%$ by 2035 A.D.; for $m_b \geq 7.0$, $< 1\%$ by 2000 A.D. and 0.2-1.0% by 2035 A.D.

The uncertainties involved in deriving the above estimates of conditional probability rank is as follows:

- (1) Choice of source zone - varies T_r by 100%;
varies P_c by $\sim 50\%$;
- (2) Choice of line-fitting technique - varies T_r by
50-70%; varies P_c by 30-40%;
- (3) Choice of standard deviation - varies P_c
by $\sim 10-25\%$;
- (4) Choice of distribution - varies P_c by $\sim 10\%$.

Items (1) and (2) above required a choice be made in order to derive final probability values. Arguments were presented for selecting (1) the large source zone and (2) least-squares regression for the final estimates. The range of the final estimates are due to items (3) and (4).

We have been careful to make clear the number of assumptions necessary to derive the above probability values. The critical data required to reduce or constrain these estimates would be event chronologies based on paleoseismic evidence. Broad zones of the embayment sediments overlying the New Madrid seismic zone have high liquifaction potential. Datable sand blows, slumps or other liquifaction features produced by pre-1811 seismic episodes and preserved in these sediments offer the best hope of obtaining more tightly constrained forecasts of the future seismic behavior of the New Madrid zone.

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TABLE 1

PREVIOUS NEW MADRID FREQUENCY-MAGNITUDE FORMULA

Authors	Data Base/ Time Period	Region	Magnitude Range	Analysis Method	$\log(M_0)$ vs $\log(M)$ or $\log(M)$ vs $\log(M)$	Av. Recurrence Time (yrs)
Muttli (1974)	Historical, 1833-1972 (140 years)	Cent. MS Valley -250,000 km ²	3.0<mb<6.2	Max. Likelihood (non-cumulative)	$\log(M_0)=3.55-0.87mb$	47 347 773
Stauder and others (1976)	Instrumental, 7/78 - 12/85 (1.5 yrs)	MMSZ, 1.5° x 1.5° -22,800 km ²	1.2<mb<4.3	Max Likelihood	$\log(M)=3.76-0.92mb$	58 497 1,117
Muttli & Herrmann (1978)	Historical, 1811-1975 233 events/168 yrs	MMSZ (A) 22,508 km ²	3.7<mb<7.4	Visual line fit	$\log(M_0)=3.20-0.75mb$	30 169 228
Historical, 1811-1975 303 events		MMSZ (A+B) 50,012 km ²	3.2<mb<7.4	-Area normalized to 100,000 km ² -b restricted to 0.92 -weighted least squares	$\log(M_0)=3.90-0.92mb$ $\log(M_0)=3.95-0.92mb$	42 347 810 37 309 721
Muttli (1979)	Historical plus Instrumental 1811-1975, 165 yrs	MMSZ	1.0<mb<7.4	-line fit: not available -area normalized to 15,000 km ²	$\log(M_0)=3.31-0.77mb$	21 120 240
Rowell (1980)	Muttli (1974) Hist. List	Cent. MS Valley -250,000 km ²	3.0<mb<6.2	Converts to cumulative; applies Omabel extreme value theory (Type 1)	$\log(M_0)=3.43-0.87mb$ $\log(M_0)=3.82-0.92mb$	69 510 1,100
Johnston (1981)	Hist. (Muttli & Brill, 1982) plus Instr. (Stauder, et.al., 1978-1980) 1816-1980/167 yrs.	MMSZ -37,500 km ² (hist) -14,400 km ² (instr)	1.7<mb<6.2	-Avg. of least squares & max likelihood -normalized time periods	$\log(M_0)=3.27-0.89mb$	118 912 1,687
Perry (1981)	Hist. (Muttli & Brill, 1982). Instr. (1974- 1980)	Muttli & Brill config. 25,891 km ² Ruas (1980) config. 32,635 km ²	1.7<mb<6.2	max likelihood	$\log(M_0)=3.132-0.873mb$	127 953 1,741
Muttli (1981)	Historical plus Instrumental	MMSZ	1.7<mb<7.2	Not available	$\log(M_0)=3.33-0.87mb$	78 525 1,050
Stauder (1982)	Instrumental	MMSZ, 1.5° x 1.5° -22,800 km ²	1.0<mb<3.5	least squares	$\log(M_0)=3.437-0.783mb$	not applicable to large events

TABLE 2

NEW MADRID FREQUENCY-MAGNITUDE PARAMETERS

Data Set/Method	Increment	a	σ_a	b	σ_b (Holt, 1982)	T_r (years) (M26.0)	T_r (years) (M27.0)
Large Source Zone							
157,700 km ² (Fig. 1)	.	.	.	.	.	.	.
956 events; 1816-1983	.	.	.	.	.	.	.
Magnitude: 1.7-6.2	.	.	.	.	.	.	.
$\Delta M_s .1$	.	3.346	($\pm .037$)	.882	($\pm .028$)	88	673
Least Squares		3.550	($\pm .070$)	.882	($\pm .030$)	55	420
							550
Small Source Zone							
29,969 km ² (Fig. 1)	.	.	.	.	.	.	.
685 events; 1816-1983	.	.	.	.	.	.	.
Magnitude: 1.7-6.2	.	.	.	.	.	.	.
$\Delta M_s .1$	.	3.187	($\pm .055$)	.896	($\pm .046$)	155	1,216
Least Squares		3.488	($\pm .095$)	.930	($\pm .043$)	124	1,052
							1,100
Maximum Likelihood							
(Bender, 1983)							
$\Delta M_s .1$		3.899	---	1.019	($\pm .053$)	164	1,714
$\Delta M_s .5$		3.851	---	1.001	($\pm .050$)	143	1,432

* Included for comparison only - see text.

TABLE 3

WEIBULL CONSTANTS

Aver. Recurrence Interval T_r (years)	Standard Deviation σ (% of T_r)	λ (rate parameter)	ν (shape parameter)	References
35	24 yr (69%)	.0061	1.41	Kiremidjian & Anagnos (1984)
87	34 yr (39%)	3.52×10^{-6}	2.70	Hagiwara (1974)
70	33%	5.69×10^{-7}	3.30	This study
70	50%	1.03×10^{-4}	2.10	This study
140	33%	5.78×10^{-8}	3.30	This study
140	50%	2.41×10^{-5}	2.10	This study
550	33%	6.32×10^{-10}	3.30	This study
550	50%	1.36×10^{-6}	2.10	This study
1100	33%	6.42×10^{-11}	3.30	This study
1100	50%	3.18×10^{-7}	2.10	This study

TABLE 4

WORLDWIDE MEAN RECURRENCE TIMES AND STANDARD DEVIATIONS

LOCATION (Reference)	Mean Recurrence Interval T_r (years)	Standard Deviation years	Standard Deviation (% of T_r)
<u>Southern San Andreas fault, USA</u> 9 events (Sieh, 1978)	164	± 76	46%
<u>Southern California, USA</u> (Sykes and Nishenko, 1984)			
Parkfield	22	± 7	32%
Pallet Creek (12 events)	145	$\pm 61-73$	42-44%
Imperial fault	32	± 10	32%
<u>Aleutian Arc, Alaska, USA</u> 28 events (Jacob, 1984)	73	± 32	44%
<u>Oaxaca, Mexico</u> (McNally and Minister, 1981)	35	± 24	69%
<u>From (Rikitake, 1977)</u>			
Nankai - Tokai, Japan	170	± 68.9	41%
Hokkaido - Kuriles Arc	85.3	± 24.6	29%
Northern South America	46.3	± 30	65%
Southern South America	100	± 22.5	23%
<u>South Kanto, Japan</u> (Hagiwara, 1974)	87	± 34	39%

TABLE 5

SUMMARY OF CUMULATIVE PROBABILITIES: 1985

Δt (years)	$T_r(\sigma=33T \text{ to } .50T_r)$ (years)	$Q_c(t=1985)$ (Gaussian)	$L_c(t=1985)$ (Log-normal)	$W_c(t=1985)$ (Weibull)	$P_c(t=1985)$ (extreme range)	$S_c(t=1985)$ (Poisson)
$mb \geq 6.0 \text{ (Ms6.3)}$						
1895 [$t-t_0=90yr$]	$70 \pm (\sigma=23-35)yr$	80-72%	83-78%	81-73%	11-83%	72%
	$140 \pm (\sigma=47-70)yr$	14.2-23.6%	11.5-24.2%	15.0-26.4%		47%
$mb \geq 7.0 \text{ (Ms8.3)}$						
1812 [$t-t_0=173yr$]	$550 \pm (\sigma=183-275)yr$	2.0-8.5%	0.3-1.3%	1.5-6.6	<<1.0-8.5%	27%
	$1,100 \pm (\sigma=367-550)yr$	0.6-4.6%	<<1.0-.011%	0.16-1.6%		15%

TABLE 6

SUMMARY OF CONDITIONAL PROBABILITIES: 1985

Δt (years)	T_r ($\sigma=33T$ to $.50T_r$) (years)	$G_r(t, \Delta t)$ (Gaussian)	$L_r(t, \Delta t)$ (Log-normal)	$W_r(t, \Delta t)$ (Weibull)	$P_r(t, \Delta t)$ (extreme range)	$\bullet P_r(t, \Delta t)$ (restricted range)	$S_r(t, \Delta t)$ (Poisson)
mb>6.0 (Ms6.3)							
15	70±($\sigma=23-35$)yr	66-44%	55-38%	67-39%	9-67%	40-63%	19.3%
	140±($\sigma=47-70$)yr	9.9-9.3%	13.5-14.8%	10.2-11.0%			10.2%
50	70±($\sigma=23-35$)yr	99-92%	94-80%	99-87%	34-99%	86-97%	51.0%
	140±($\sigma=47-70$)yr	42-34%	51-46%	42-37%			30.0%
mb>7.0 (Ms7.3)							
15	550±($\sigma=183-275$)yr	0.44-0.97%	0.05-0.75%	0.5-1.3%	<<1.0-1.3%	0.3-1.0%	2.7%
	1,100±($\sigma=367-550$)yr	0.07-0.28%	<<1.0-0.01%	0.05-0.30%			1.4%
50	550±($\sigma=183-275$)yr	1.8-3.5%	0.4-3.4%	2.0-4.7%	<<1.0-4.7%	2.7-4.0%	8.7%
	1,100±($\sigma=367-550$)yr	0.27-1.0%	<<1.0-0.07%	0.2-1.1%			4.4%

* see text

FIGURE CAPTIONS

Figure 1. Map of the Central United States with the 1974-1983 instrumental seismicity data set (Stauder and others, 1974-1983). The boundaries of the two source zones used for frequency-magnitude determination are : large zone, 35.0° - 39.0° N/ 87.7° - 91.5° W; small zone, 35.0° - 37.0° N/ 89.0° - 91.5° W.

Figure 2. Cumulative frequency-magnitude data base for determining the Gutenberg-Richter constants, a and b. Instrumental data from 1974-1983 was used for $m \leq 3.5$; historical data for $m \geq 3.6$. Open symbols denote data points not used in computation. (a) Data base from large source zone of Fig. 1. (b) Data base from small source zone. See Table 2 for computed recurrence formula from these data.

Figure 3. Illustration of the effect of varying Δm , the magnitude increment. Magnitude increments of 0.1 and 0.5 are shown.

Figure 4. (a) An arbitrary distribution function illustrating the concept of $f(t)$, the probability density function and $F(t)$, the cumulative probability function. Note that for normalized or standard distributions the total area between $f(t)$ and the abscissa is 1. (b) Formulation of conditional probability P_c in terms of the ratio of two areas beneath a standardized probability density function.

Figure 5. Conditional probability by approximate and exact methods. The Gaussian distribution for an $m_0=6.0$ quake is chosen for this illustration. The approximation method is the first-order Taylor expansion of the cumulative probability (equations 10 and 11); the exact method is the ratio of areas (equations 8 and 9). Note that the first-order approximation is a good representation of conditional probability only for small Δt and for elapsed times t less than

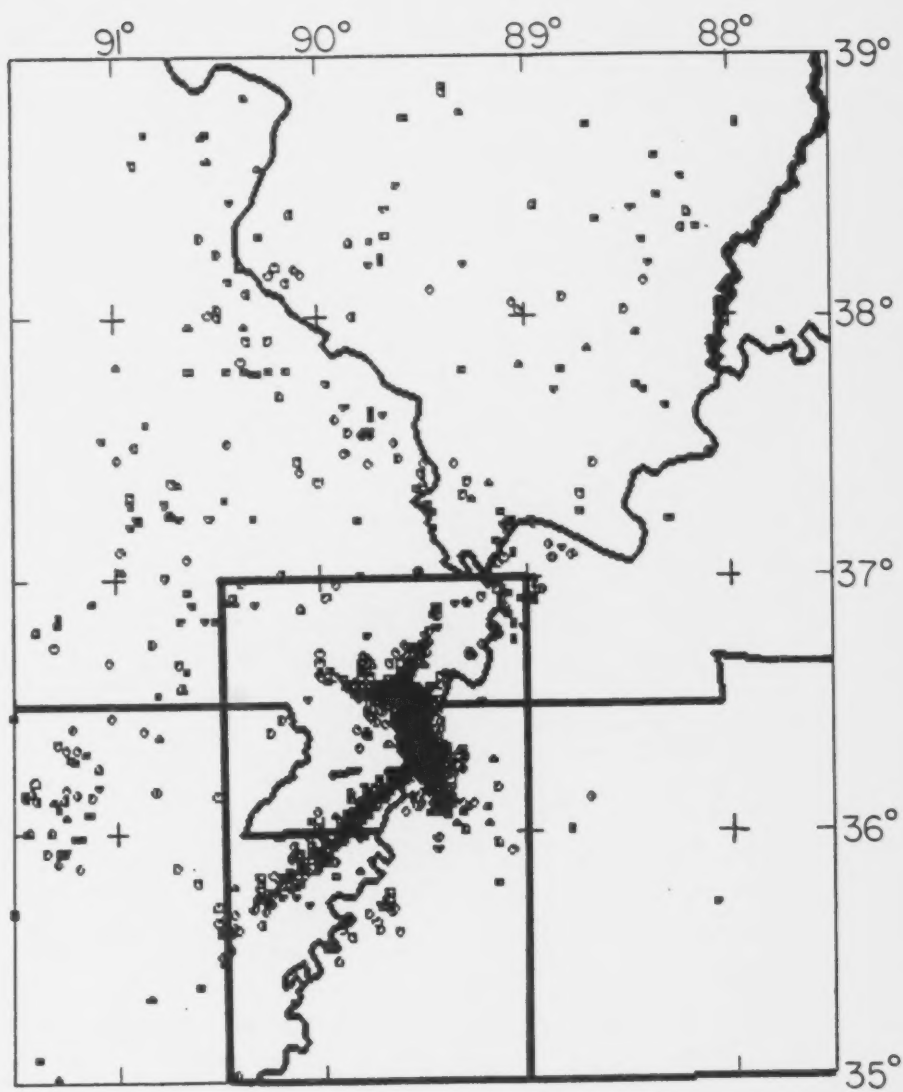
T_r , the average repeat time.

Figure 6. Observed interoccurrence times of the instrumental New Madrid data set. A Poisson distribution function in terms of interevent times (equation 12) is shown for comparison.

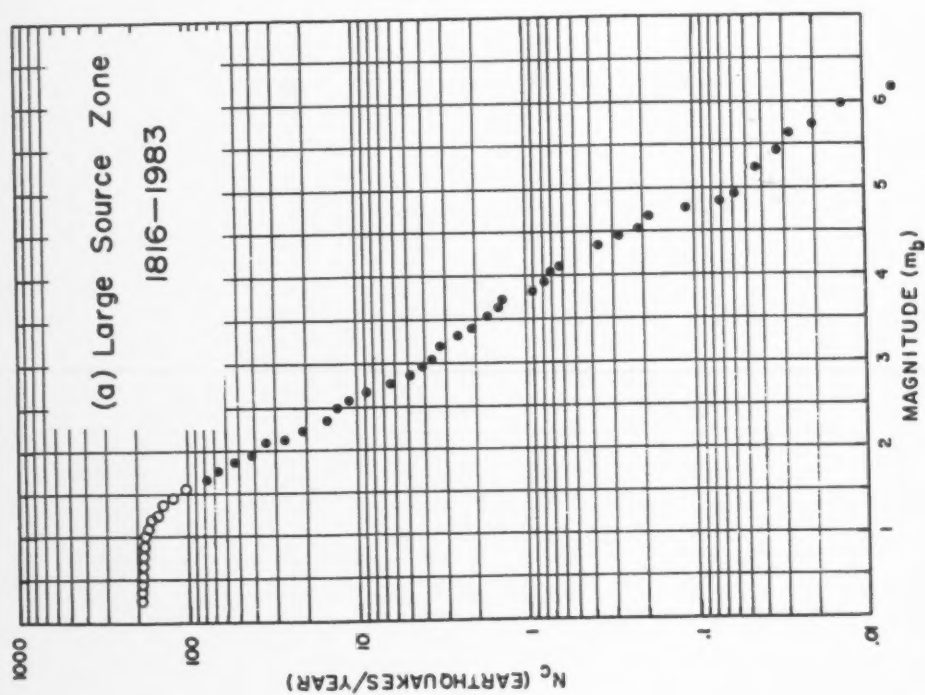
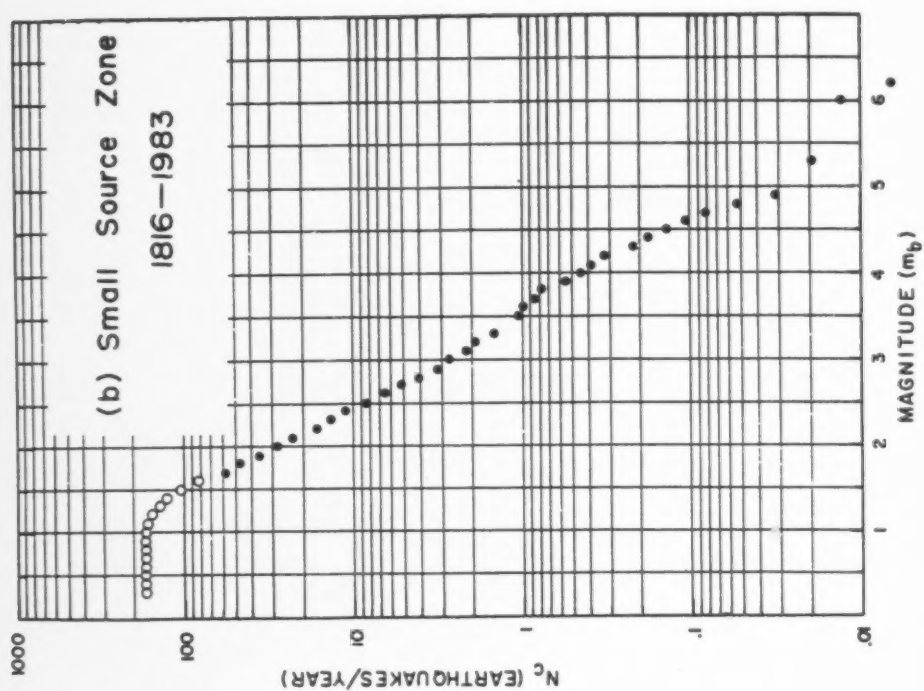
Figure 7. Logic tree of the five parameters which are allowed to vary to obtain a range of estimates of conditional probability P_c . The branches are labeled as follows: (1) is for a magnitude range of $m_b 6.0-7.0 (M_s 6.3-8.3)$; (2) average recurrence interval (yrs); (3) standard deviation as a percentage of the average recurrence interval; (4) the assumed probability distribution; (5) time increment in years over which conditional probabilities apply.

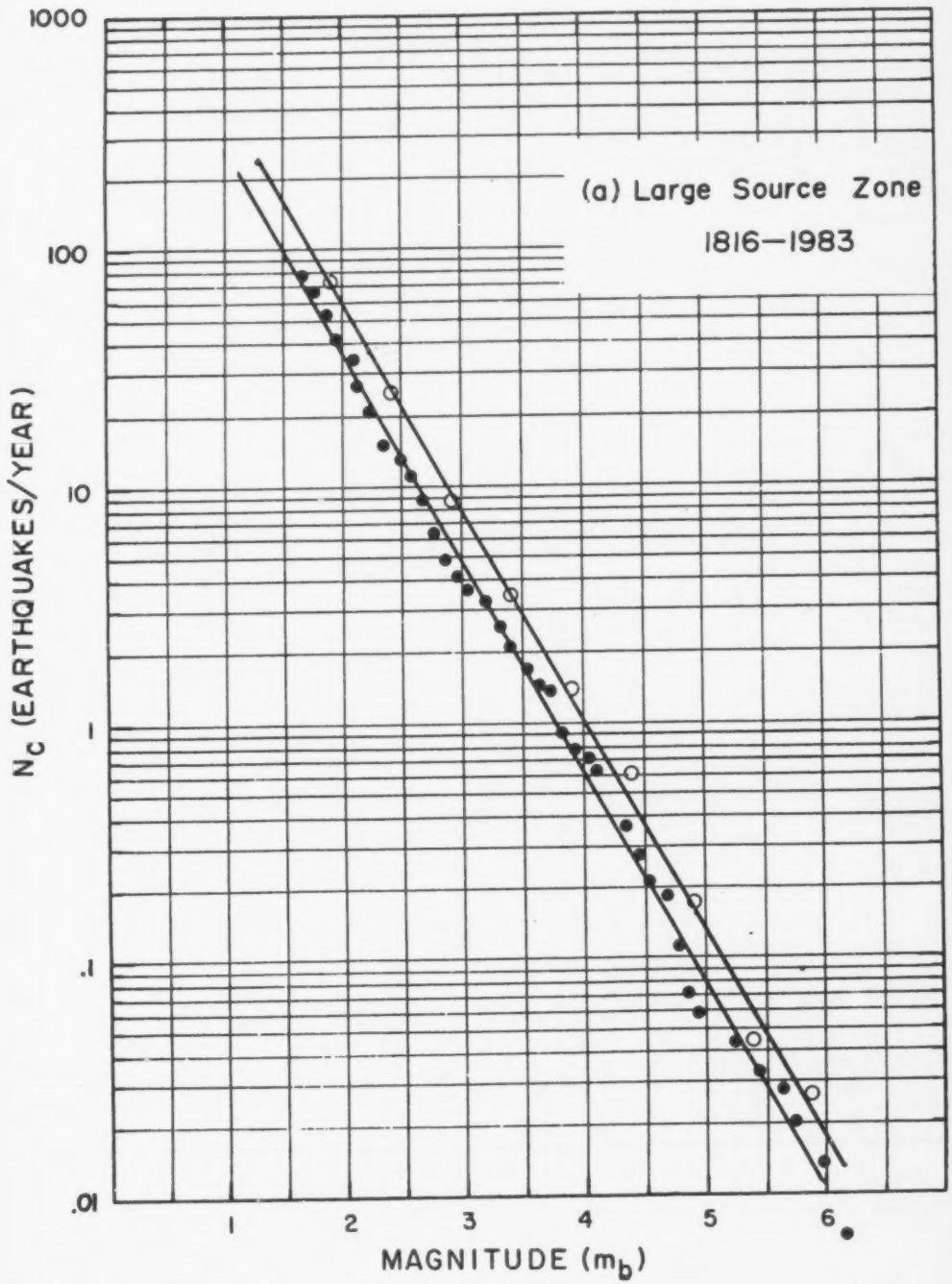
Figure 8. (a) Cumulative probabilities for the four distributions considered in this study for the representative case of a quake $m_b \geq 6.0$, mean recurrence time T_r of 140 years, standard deviation of $T_r/3$. The Gaussian and Weibull distributions are nearly identical in this case. (b) Illustration of the variation of cumulative probabilities with T_r and σ for a quake $m_b \geq 7.0$ for the Poisson and Gaussian distributions. The Weibull and log-normal distributions would vary a relatively minor amount from the Gaussian.

Figure 9. Computed conditional probabilities for the various parameters shown in the parameter tree of Figure 7. (a) Mean recurrence interval, $T_r=70$ years; (b) $T_r=140$ years; (c) $T_r=550$ years; (d) $T_r=1,100$ years. Poisson conditional probabilities are shown for reference only. See text for discussion.

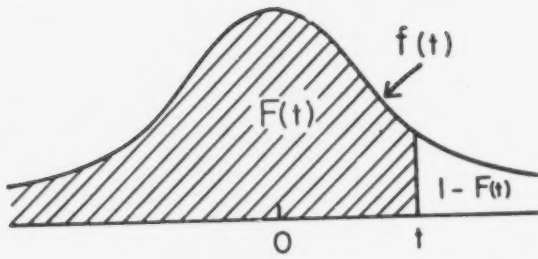


1974 - 1983

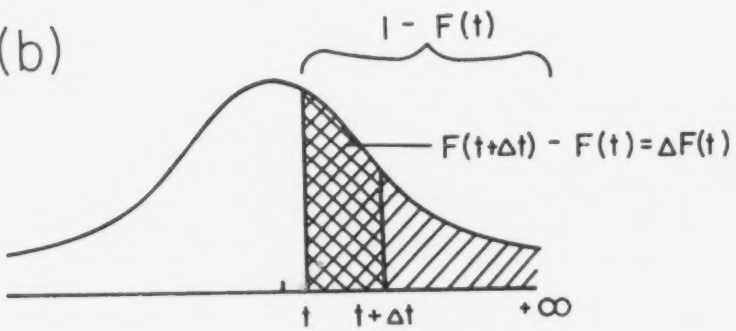




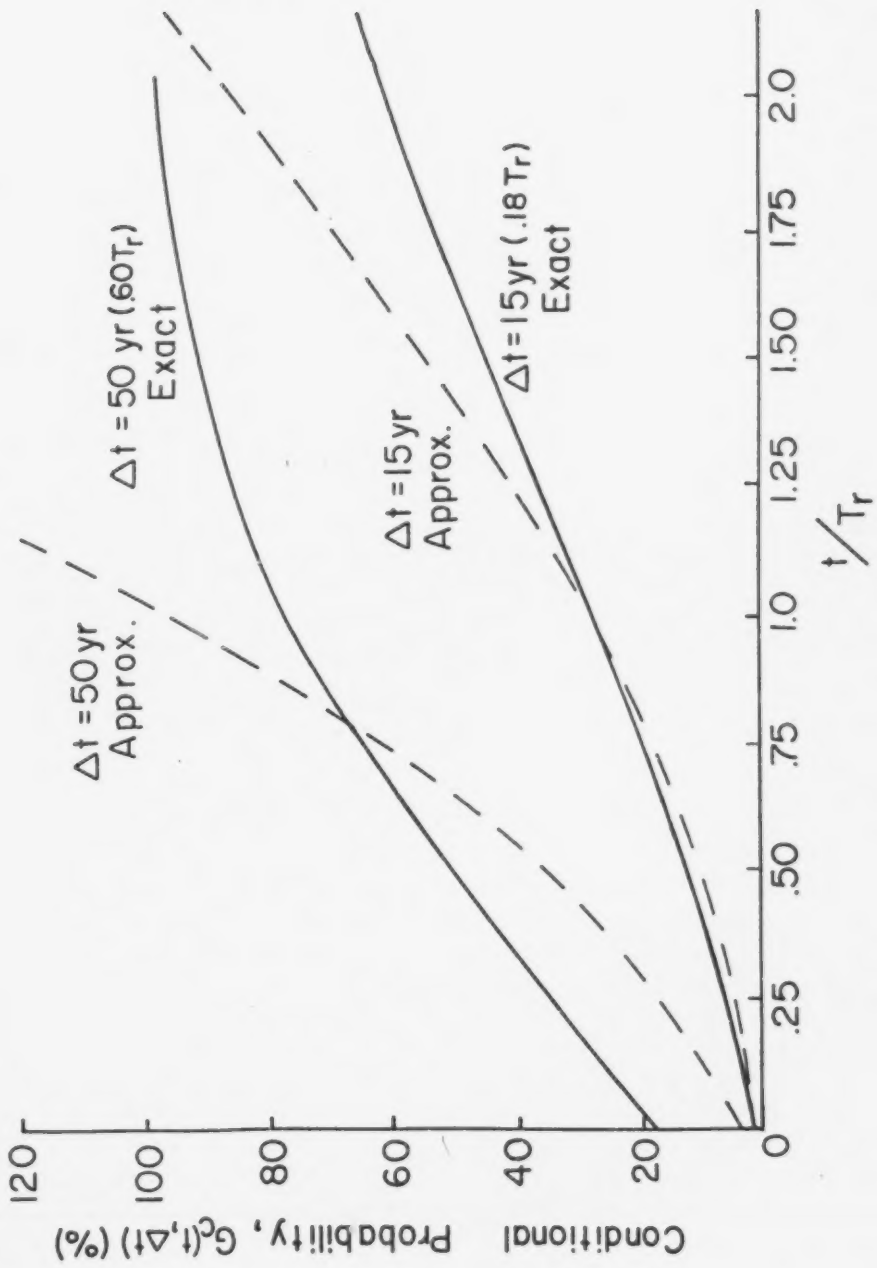
(a)

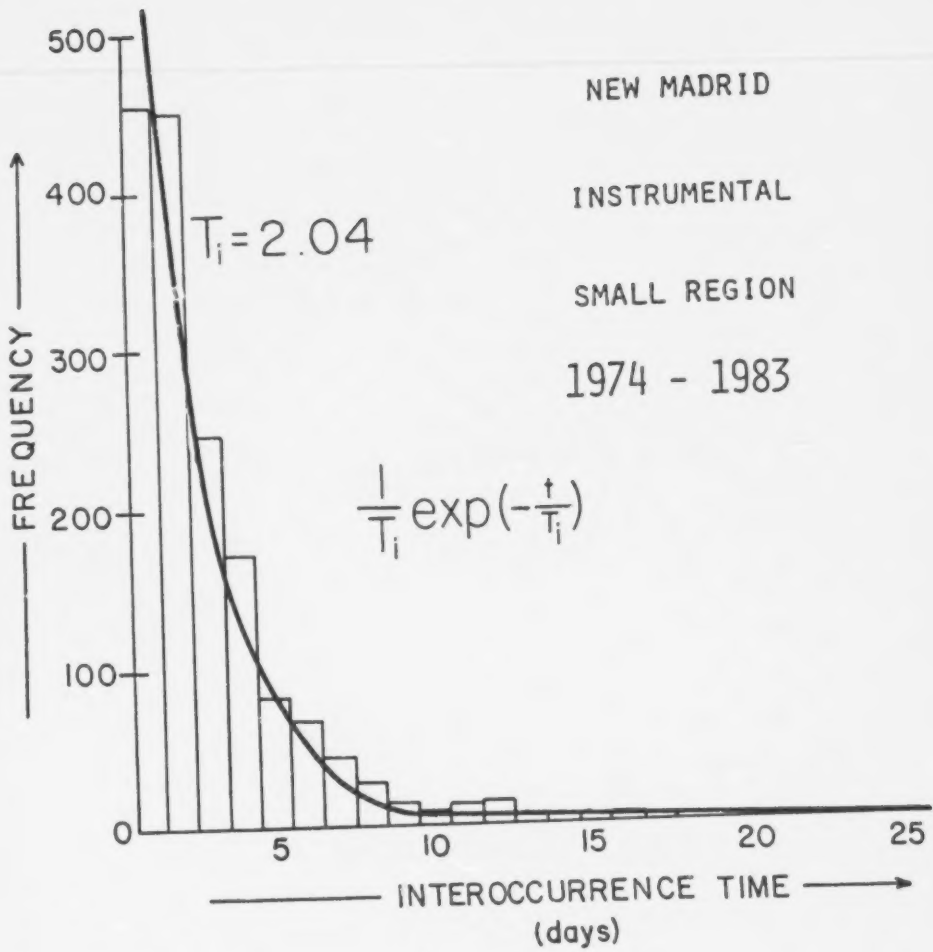


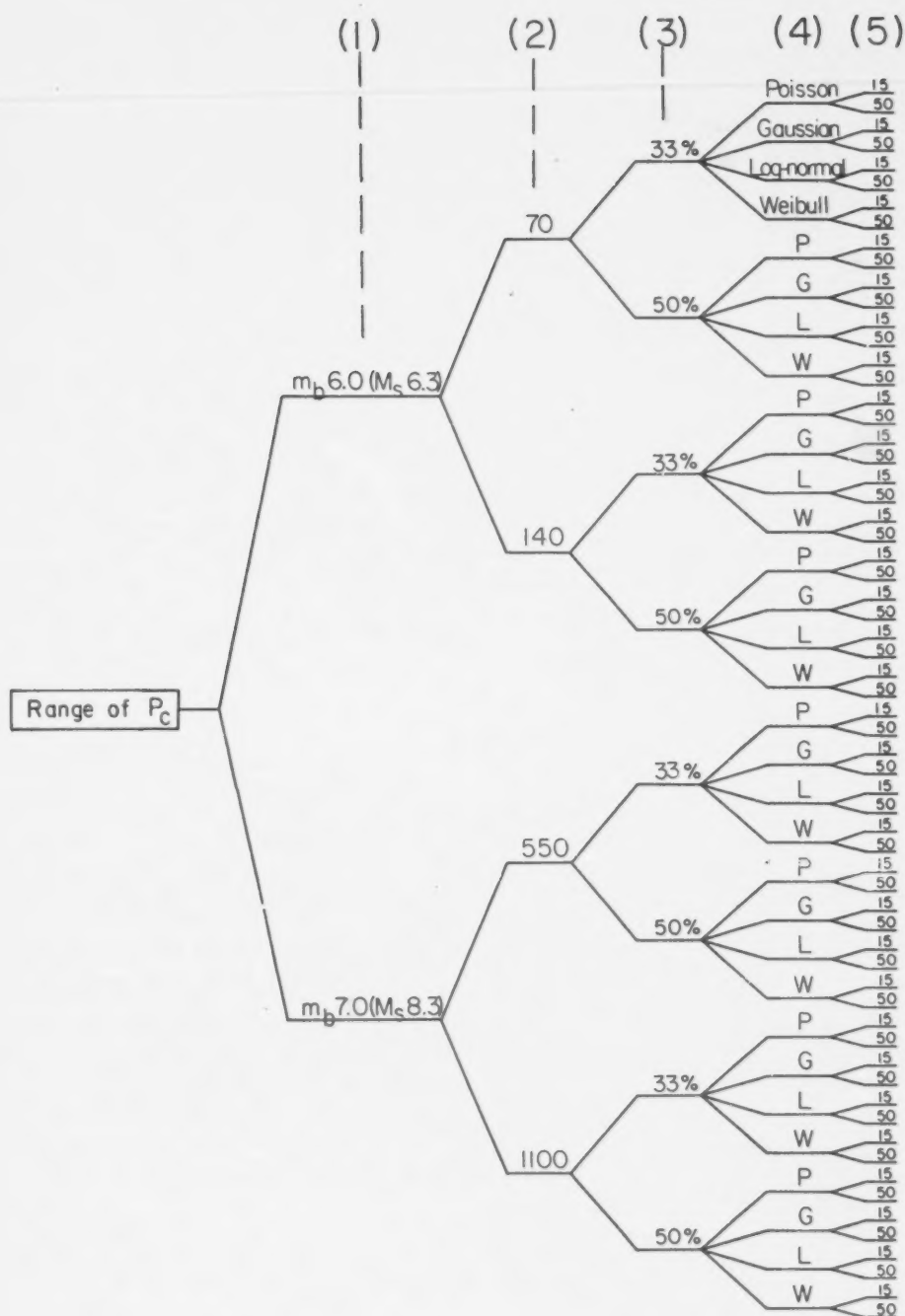
(b)

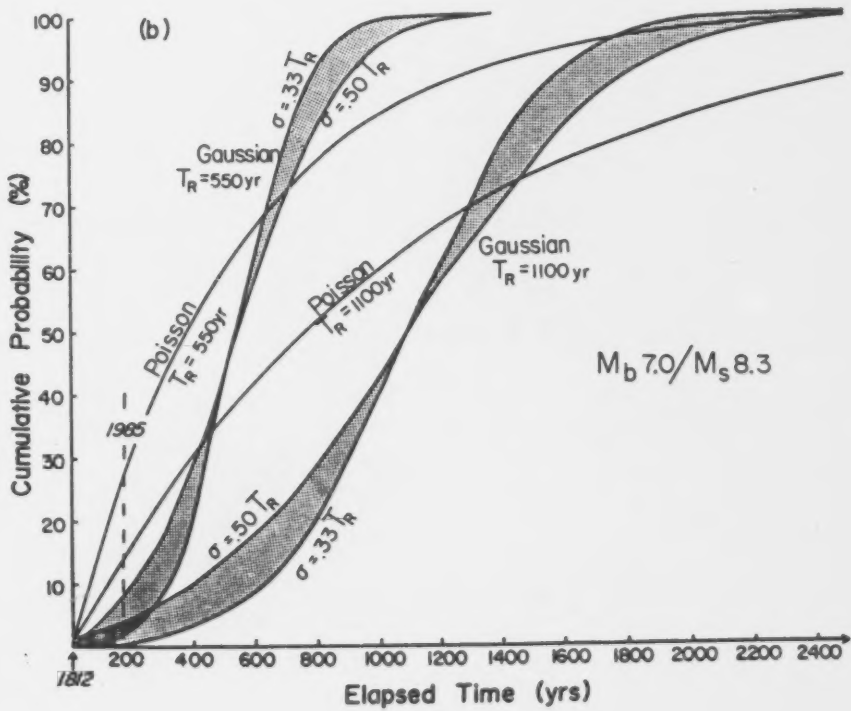
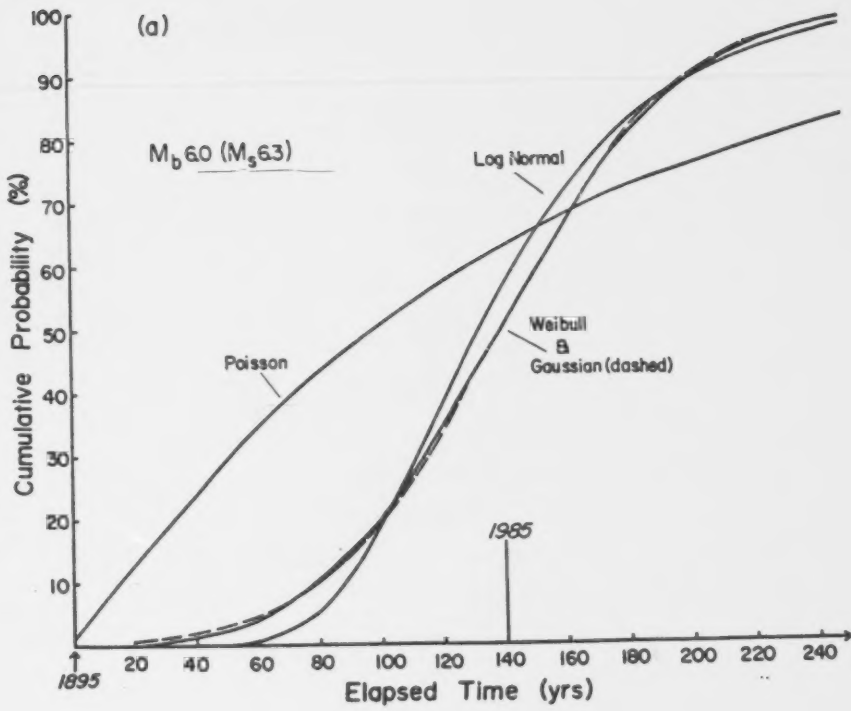


$$P_c = \frac{\Delta F(t)}{1 - F(t)}$$





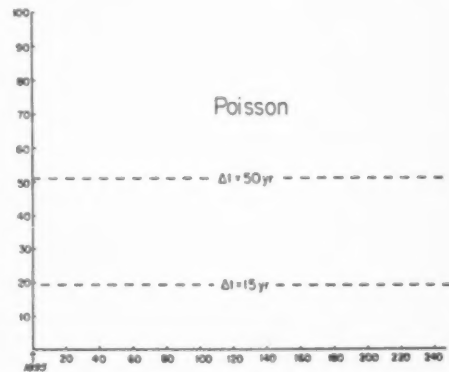
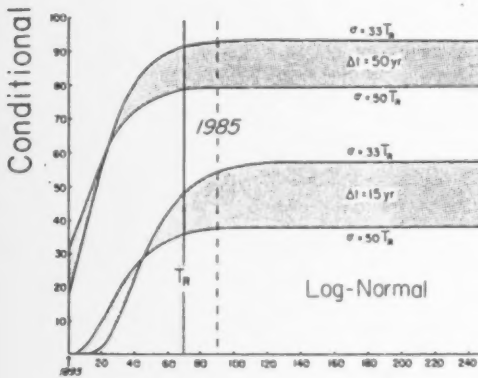
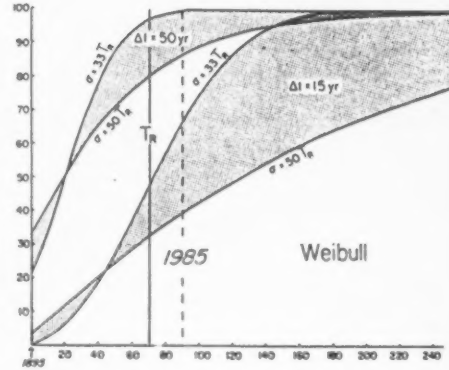
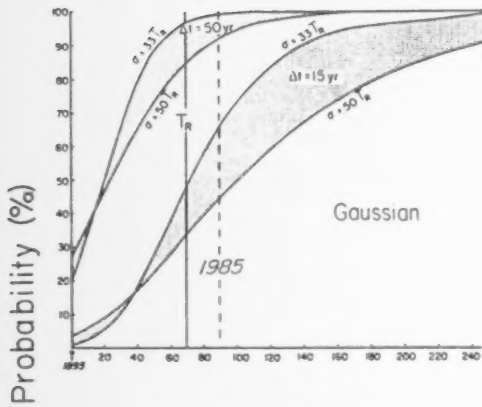




$$M_b 6.0 / M_s 6.3$$

 $T_R = 70 \text{ years}$

Last Occurrence: 1895

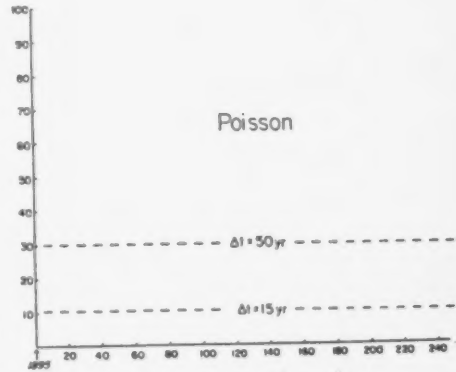
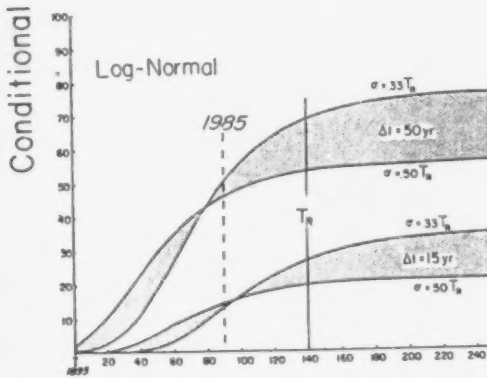
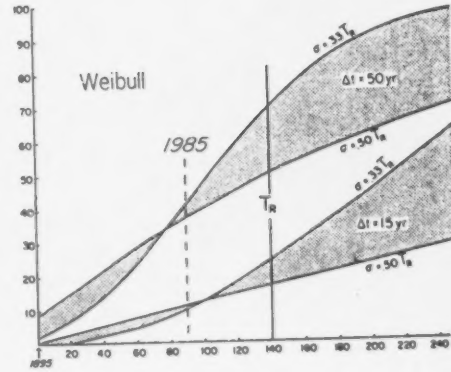
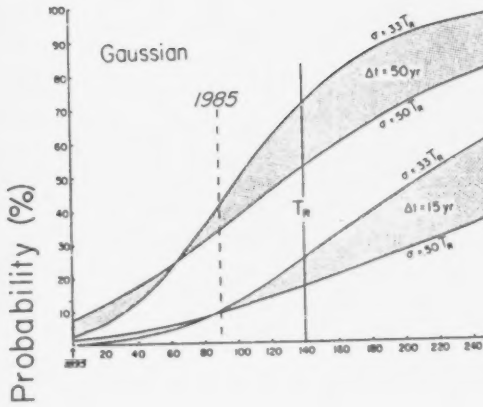


Elapsed Time since Last Event (yrs)

$$M_b 6.0 / M_s 6.3$$

 $T_R = 140 \text{ years}$

Last Occurrence: 1895

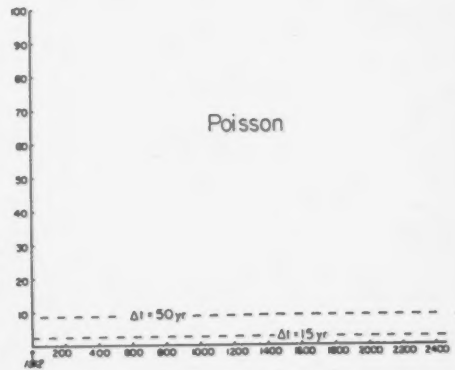
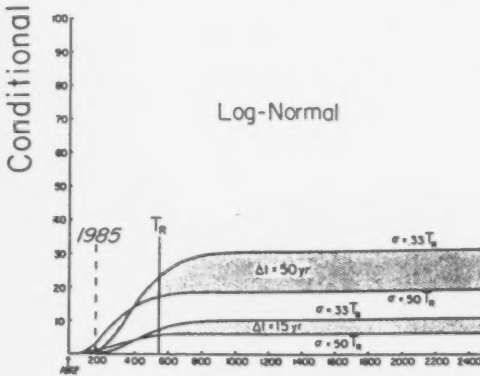
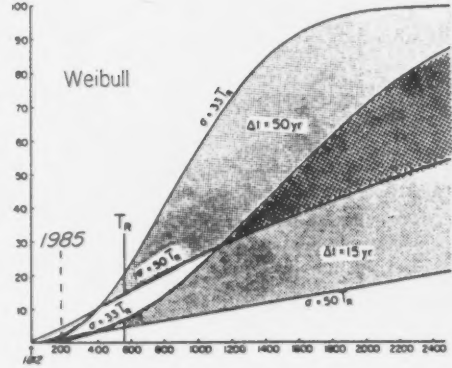
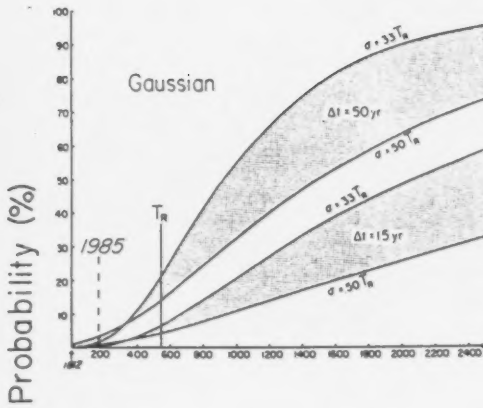


Elapsed Time since Last Event (yrs)

$$M_b 7.0 / M_s 8.3$$

 $T_R = 550 \text{ years}$

Last Occurrence: 1812

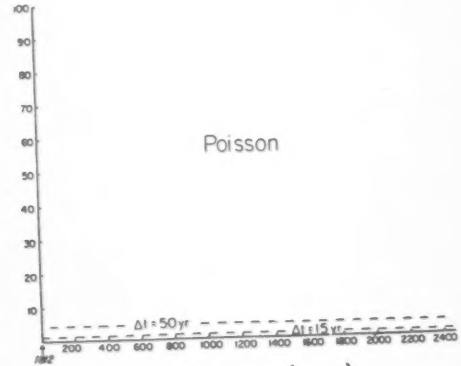
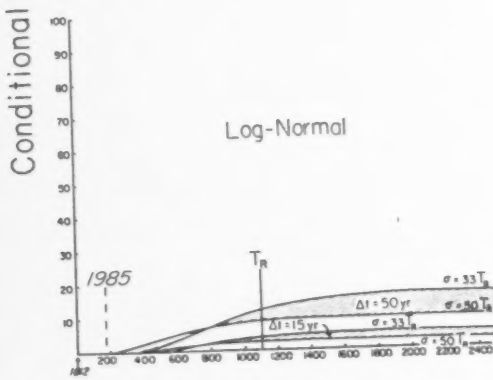
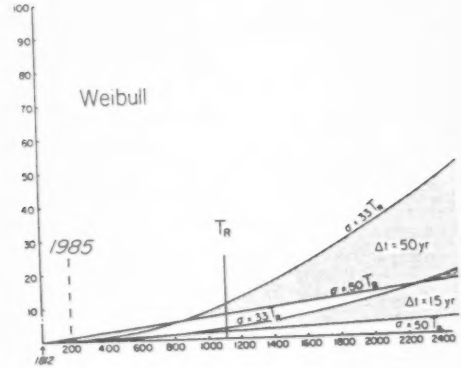
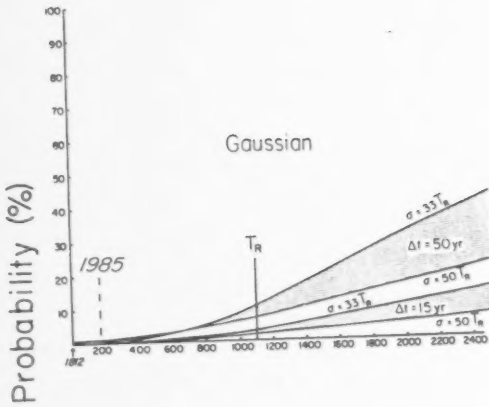


Elapsed Time since Last Event (yrs)

$$M_b 7.0 / M_s 8.3$$

 $T_R = 1,100 \text{ years}$

Last Occurrence: 1812



Elapsed Time since Last Event (yrs)

APPENDIX II

Subcommittee on Investigations and Oversight
Subcommittee on Science, Research and Technology

CHARTER

Joint Hearing on
Damage Projections for Future Eastern Earthquakes

Date & Time: 10:00 a.m., September 12, 1984

Place: 2318 Rayburn House Office Building

Objectives:

1. To examine the status of scientific research on the ability of the structures and lifeline systems to withstand earthquakes in Eastern United States.
2. To review the damage projections of future earthquakes.
3. To explore the areas where additional research is needed.

Background:

Earthquakes are not merely a West coast phenomenon. There are regions classed as having at least moderate seismic risk in more than 39 of the 50 states of this country. The most severe historic earthquake in the contiguous United States occurred not in California but as one in the series that struck New Madrid, Missouri, in 1811 and 1812. Furthermore, the area of comparable damage in a severe eastern earthquake is much larger than in a western one of the same magnitude and could simultaneously threaten widely separated facilities. Therefore, earthquake hazards must be taken into account in lifeline and structure design and construction regardless of where the facility is located. (Lifeline systems include energy, water, transportation, and

communication)

On May 23, 1984 the Subcommittees held a joint hearing on earthquakes in the Eastern United States. Witnesses testified that a study of several cities, near the New Madrid fault, documented that they were susceptible to severe damage by future earthquakes. Dr. Otto Nuttall of Saint Louis University stated that the stress currently built up in the fault, if released today, would produce an earthquake of magnitude 7.6 on the Richter Scale. This could cause major damage to oil, gas, water, and sewage pipelines. Additionally, dams, power and telephone lines, bridges, and transportation could be damaged beyond the point of usefulness.

Lifeline Systems:

Lifeline systems such as natural gas and oil pipelines, water sewage lines, and subsurface tunnels, in general, are severely damaged during strong earthquakes, presenting public health and safety hazards and causing severe disruption within the area and beyond. For example, in the 1906 San Francisco earthquake, extensive fire damage and epidemics resulted from disruption of water supply and the loss of potable water respectively. Water, sewer and natural gas transmission systems were seriously damaged in the major earthquakes in Alaska (1964), San Fernando Valley (1971), and Coalinga, California (1983).



The importance of research in "earthquake proof" lifeline systems has been well recognized in recent years. Providing answers on technical issues is important to several critical and high-technology industries including utility companies, local, state and federal agencies.

One strategy, often called the most cost-effective procedure, is to start introducing seismic resistance in all new construction as soon as possible, as opposed to the retrofitting of older structures. If the next major earthquake does not occur for 100 years, the East would be essentially earthquake proof because all structures would have been replaced within this time.

Buildings & Structures: The great majority of existing buildings in the east were not specifically designed to resist earthquakes. Thus, in the event of a

major earthquake, the greatest loss of life would result from partial or total structural building collapse. However, some of the buildings in coastal areas were designed to withstand strong wind forces and as a result would have a fair to good seismic resistance. In addition, many buildings built by the federal government in earthquake-prone areas are required to have seismic resistance.

One important aspect of earthquake preparedness is that it can be cost effective. For example, one Tennessee consulting firm estimated that ten lives could be saved, during an earthquake of an intensity of IX on the modified Mercalli intensity scale (about 6.5 - 7.0 on the Richter scale) for each million dollars spent on protection. This was based on the average claim for damages in disasters such as the MGM Hotel fire in Las Vegas, Nevada.

Water: Most water and energy structures, such as dams in Central United States have not been designed to withstand earthquakes. As a result, a substantial number of dam failures can be expected in any major eastern earthquake.

The U.S. Army Corps of Engineers has surveyed the safety of dams in Central United States and has found many unsafe.

High Hazard Dams in the Central U.S.

	<u>High Hazard</u>	<u>Unsafe</u>	<u>Urgent</u>
Missouri	644	389	42
Illinois	125	20	1
Indiana	235	68	3
Kentucky	210	75	5
Tennessee	145	66	2
Arkansas	129	39	2
Mississippi	77	36	4

A High Hazard dam is one whose failure would cause substantial loss of life.

An Unsafe dam is one judged to be inadequate structurally to withstand expected earthquakes.

Urgent dams denotes those facilities which are judged to pose imminent failure risks which must be resolved immediately. This includes dams with inadequate spillway capacity, degraded structural properties, or a variety of other defects.

Pipelines: Many interstate natural gas and petroleum product pipelines pass through the Central United States near the New Madrid fault zone. Other major lifelines (railroads, telecommunications, inland waterways, electric power networks) are similarly located. The important characteristic of damage to many of these facilities is that the secondary costs of their damage such as interruption of service, fire, etc. far exceed the loss to the facility itself.

Energy and Nuclear Facilities: A key element in the design criteria for nuclear facilities is the seismic shock that must be accommodated by the nuclear facility and its contained equipment. The intensity X on the modified Mercalli scale (approximately 7.0 - 7.3 on the Richter scale) earthquake that

occurred near Charleston, South Carolina, in 1886 is by far the largest earthquake experienced along the eastern seaboard. Future large earthquakes are certainly possible elsewhere along the eastern coast. Inclusion of an earthquake of this magnitude in the construction considerations would lead to significantly higher design values than otherwise might be used. This concept applies to the Department of Energy facilities at Savannah River and the gaseous diffusion plant in Paducah, Kentucky, which is near the New Madrid fault.

HEARING

The hearing will explore the earthquake preparedness of many of the lifeline systems located in earthquake zones in Eastern United States. Witnesses from the federal agencies and the scientific community will testify on the damages earthquakes might cause and on what additional research needs to be done to insure "earthquake proof" lifeline systems.

APPENDIX III



Federal Emergency Management Agency

Washington, D.C. 20472

May 23, 1984

Honorable Albert Gore, Jr., Chairman
 Subcommittee on Investigations and Oversight
 Committee on Science and Technology
 House of Representatives
 Washington, D.C. 20515

Dear Mr. Gore:

In response to your written request and our discussions during the oversight hearings this morning, I am enclosing for your use a copy of the draft study "An Assessment of Damages and Casualties for Six Cities in the Central United States Resulting from a Great Earthquake in the New Madrid Seismic Zone".

A final draft of the report was submitted to the Federal Emergency Management Agency (FEMA) in December 1983 by the engineering firm performing the study. FEMA, upon receipt of the draft, and with the concurrence of the six States impacted, initiated a review of the study among public and private sector experts in the field of earthquake vulnerability assessments and geologic characteristics of the New Madrid system. Our purpose in this review was to assure an acceptable and technically defensible product that could be used as a basis for preparedness activities and further earthquake vulnerability assessment in the central United States.

FEMA is presently negotiating with the engineering firm to revise the draft to reflect the results of the technical review. The report will address a 7.6 magnitude earthquake event scenario as well as the 8.6 magnitude event upon which the report is based. The 7.6 earthquake is the more likely event based on current geologic data, while the 8.6 event is considered to be comparable to the greatest historical seismic events in the area, which occurred during the winter of 1811-1812. The report will also be revised to incorporate editorial changes.

I am also enclosing for your reference, copies of the comments received from the other Federal agencies and Dr. Nuttli (and our response to him). If you have any questions on the draft report or the comments, please do not hesitate to contact me.

Sincerely,

Samuel W. Speck
 Associate Director
 State and Local Programs
 and Support

Enclosures

TABLE
MODIFIED MERCALLI INTENSITY SCALE

<u>Intensity</u>	<u>Description</u>	<u>PGA Interval</u> ¹ (g units)
I.	Not felt except by a few under especially favorable conditions.	0.03
II.	Felt only by persons at rest in places such as upper floors of buildings. Delicately suspended objects swing.	0.03
III.	Felt by many persons in places such as upper floors of buildings but of a degree that most persons do not recognize it as an earthquake. Standing automobiles may rock slightly as if from vibration caused by a passing truck. Duration may be measured.	0.03
IV.	In daytime, felt by many indoors but by only a few outdoors. Dishes, windows, doors disturbed, and walls creak. Sensation like a heavy truck striking a building. Standing automobiles rocked considerably.	0.03
V.	Felt by all, many awakened. Some dishes and window glasses broken, wall plaster may crack. Unstable objects overturned. Disturbance of telephone poles, trees and other tall objects sometimes noticed. Pendulum clocks stopped.	0.03-0.08
VI.	People are frightened and run outdoors. Heavy furniture may be moved; some instances of fallen plaster and toppling of chimneys. Slight damage.	0.09-0.15
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in ordinary structures, and considerable in poorly built or badly designed structures. Chimneys broken. Felt in moving automobiles.	0.16-0.25
VIII.	Some damage even in buildings of good design and construction. Considerable damage in ordinary buildings, with some collapsing. Great damage in poorly constructed buildings. Panel walls thrown out of frame structures. Falling of houses and factory chimneys, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Hinders driving of automobiles.	0.26-0.45

<u>Intensity</u>	<u>Description</u>	<u>PGA Interval¹</u> (g units)
IX.	Damage considerable in buildings of good design and construction. Structures thrown out of alignment with foundations. Ground cracked conspicuously. Underground pipes damaged.	0.46-0.60
X.	Wooden houses of good design and construction collapse. Most masonry and frame structures destroyed together with foundations. Ground cracked causing damage. Rails bent. Slopes and embankments slide. Water surface rises.	0.61-0.80
XI.	Almost all masonry structures collapse. Bridges destroyed. Fissures over entire surface of ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent prominently.	0.81-0.90
XII.	Damage total. Waves seen transmitted at ground surface. Topography changed. Objects thrown into air.	0.91
1.	PGA Interval (g units) from: McCann, M.W., Sauter, F., and Shah, H.C., 1980	



United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

In Reply Refer To:
Mail Stop 905

Received 1/4/84

Mr. Richard Krimm
Assistant Associate Director
Federal Emergency Management Agency
Office of Natural and Technological Hazards
State and Local Programs and Support
500 C Streets, S.W.
Washington, D.C. 20472

Subject: Review of Report on Potential Earthquake Damage in the Mississippi Valley Region

Dear Mr. Krimm: *Wick*

As requested, we have reviewed the draft report on potential earthquake damage in the Mississippi Valley region prepared by Allen and Hoshall, Inc. and Jack R. Benjamin and Associates, Inc. for Region VII of the Federal Emergency Management Agency. Our comments are contained in the attachment.

Although the methodology can be critized, we believe that the report provides reasonable preliminary estimates of damage that can be used to guide planning for a potential catastrophic earthquake in the Central United States. This work should be considered as a first step, not the last step, in loss estimation in the Central United States.

Sincerely yours,

John R. Filson
John R. Filson
Chief, Office of Earthquakes,
Volcanoes, and Engineering

Attachment

—Attachment

Review of Report, "An Assessment of Damages and Casualties for Six Cities in The Central United States Resulting From a Great Earthquake In The New Madrid Seismic Zone."

I. Purpose of the Report

The purpose of the report is to provide preliminary estimates of potential damage from earthquake in the Mississippi Valley region that can be used to guide predisaster planning, preparedness, and response. The report specifies the potential vulnerability of 16 types of structural systems common to cities of the Mississippi Valley region (shear-wall buildings (1-5 stories and 6 stories or greater) bearing-wall buildings, wood frame buildings, pre-engineered metal buildings, pre-cast buildings, emergency power units, water/sewage plants, power plants, electrical switchyard equipment, earth dams, major bridges, highway bridges, cylindrical storage tanks, and elevated storage tanks). Estimates of potential damage to these facilities are particularly useful for planning disaster relief and recovery in the Central United States.

Site- and structure-specific estimates of damage are beyond the scope of the report.

II. The Methodology: Strong Points and Problems

In this study, general or "best estimate" fragility curves were determined for each of the 16 types of structures (structural systems) listed above. Fragility curves are a graphical relationship which describe the probability of failure at various level of ground shaking and are the heart of the methodology used in the study to obtain preliminary estimates of damage. Fragility curves have been described in the literature and are considered by the engineering community to be a reasonable procedure for estimating potential damage. The quality of the estimates is a function of the degree to which the uncertainties, listed below, are eliminated.

The authors correctly point out the difficulties inherent in using fragility curves:

1. Uncertainty in the actual state of damage that will induced in a structural system by a particular level of ground shaking (expressed either in terms of Modified Mercalli Intensity or peak ground acceleration).
2. Uncertainty in converting from Modified Mercalli Intensity to peak ground acceleration (see figure 1). (The large degree of uncertainty in this relationship is the most critical aspect of the loss estimation methodology used in this report.)
3. Uncertainty in the correlation of the state of damage and peak ground acceleration. Most investigators agree that peak ground acceleration does not correlate well with damage except for high frequency structural systems.

4. Uncertainty in the effects of soil conditions on ground shaking, especially for intense levels of ground shaking (e.g., MMI VIII-X).
5. Uncertainty in the duration of shaking, a ground motion parameter that significant affects the degree of damage. The duration of shaking in California and the Mississippi Valley will be greatly different for the same value of MMI.
6. Uncertainty in the completeness and uniformity of the inventory of structural systems exposed to the ground shaking.
7. Uncertainty in the "best estimate" fragility curves (based primarily on California data) when applied in the Mississippi Valley
8. The need for considerable engineering judgment in the manner in which the limited data on damage from past earthquakes, especially in the Central United States, have been applied to this problem. Judgment enters into the specification of the five states of damage (nonstructural damage; slight, moderate, and severe structural damage; and collapse) and the specification of "good," "bad," and "average" structural systems of a specific type.

III. Damage Assessment

1. The report does not correctly describe the "project" earthquake for which the U.S. Geological Survey (USGS) developed the distribution of intensities. The "project" earthquake is described (page 21) as "a maximum-type or 'great' earthquake, which was postulated to occur anywhere along the known active portions of the New Madrid fault system. This earthquake was generally assumed to be equivalent in strength to the greatest of the 1811-1812 shocks, of Richter magnitude approximately 8.6."

The scenario earthquake intensity distribution or "great earthquake" developed by USGS, in fact, represents a composite shaking map assuming that the largest of the 1811-1812 sequence could occur anywhere along the northeast-southwest-striking zone. This zone encompasses the best estimates of the macroseismic zones of the three 1811-1812 events.

2. The figures from the USGS report used in the damage assessment report should be so referenced.
3. The USGS report did not "predict" ground motions as stated in the report but provided scenario estimates of the possible maximum ground motions.
4. The USGS group involved in the study should be referenced as U.S. Geological Survey, Office of Earthquakes, Volcanoes and Engineering, Denver, Colorado, rather than as "Earthquake Prediction Center, Golden, Colorado (page 14 of report).

IV. Conclusions

Estimating losses from potential earthquakes is a complex task. Although the methodology used in this study has some uncertainties, it appears to be a reasonable procedure for obtaining preliminary estimates of damage to the 16 structural systems that are common to cities in the Mississippi Valley region. These estimates can be used to guide planning for mitigating the effects of major earthquakes in the Central United States. As stated above, the damage estimates are not site- or structure-specific.

The principal criticisms of the report are:

1. The damage-assessment methodology used in the study represents only one particular point of view and differs from the approach used in other studies of potential earthquake losses (for example, the San Francisco, Los Angeles, Puget Sound, and Salt Lake City studies).
2. Because of the uncertainties inherent in the methodology based on fragility curves and the inability to quantify "engineering judgement," the loss estimates given in the report should be considered as preliminary.
3. The report should clearly state that no site- or structure-specific estimates are being provided; only "best estimates" for a structural system. (This disclaimer will be overlooked by the public unless it is stated over and over again.)
4. No standard procedure exists for estimating potential losses from earthquakes.
5. The results of this study can not be compared directly with the results obtained from a "standard" procedure (since one does not exist) or from the procedure used in other areas. Therefore, the accuracy of the preliminary loss estimates in the Mississippi Valley region can not be determined without a great deal of further study and research encompassing the entire process (from inventory to definition of the states of damage using damage data induced in structural systems similar to those in the Mississippi Valley region from earthquakes throughout the World). The best data to validate the loss estimates would be damage data in the Mississippi Valley region; these data are not available.
6. According to our understanding, the loss estimation study was performed in a relatively short time and with limited funding. Consequently, the loss estimates produced by this study should be treated as preliminary and so labeled in the report.

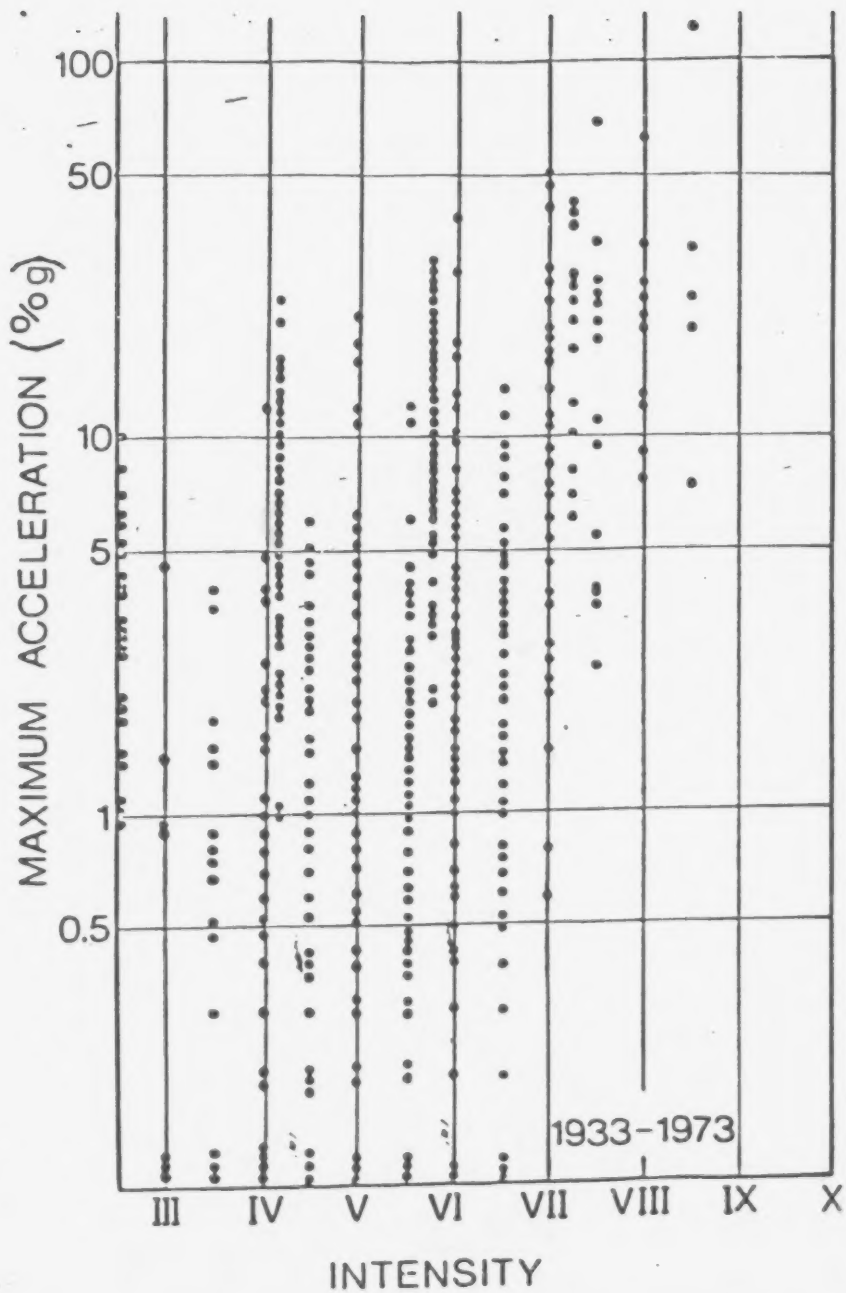


Figure 1.--Scatter diagram showing the correlation between peak ground acceleration and Modified Mercalli Intensity.

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D. C. 20540

December 16, 1983

Mr. Richard W. Krimm
Assistant Associate Director
Office of Natural and Technological
Hazards Programs
Federal Emergency Management Agency
Washington, D. C. 20472

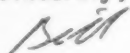
Re: Report "An Assessment of Damage
and Casualties for Six Cities in the
Central United States Resulting From
A Great Earthquake in the New Madrid
Seismic Zone"

Dear Dick:

I have received your request of December 14 to review the methodology
in the referenced report that was prepared by Allen & Hoshall, Inc.

While NSF personnel are not in a position to make such an evaluation,
we are familiar with several individuals that are very knowledgeable
in this technical area. If you are interested in contacting them, we
will be pleased to provide you with names, addresses, etc.

Sincerely,



William S. Butcher
Director
Division of Civil and
Environmental Engineering

MARCH 05, 1984

Emergency Management Branch
Construction-Operations Division

Mr. Dave McLoughlin
Acting Associate Director
Office of the Associate Director
State and Local Programs and Support
Federal Center Plaza
500 C Street, S.W.
Washington, D.C. 20472

Dear Mr. McLoughlin:

By instruction provided in FEMA Region VII letter of October 28, 1983, my responses to two Central United States Earthquake Preparedness Project related taskings are forwarded to you.

If we may be of further assistance please contact Mr. Frank Stubbs, Chief, Emergency Management Branch, (bdl) 634-5816.

Sincerely,

/s/ JOSEPH A. YORE

Enclosures

William E. Read
Major General, U.S. Army
Division Engineer

Copy Furnished:

✓ DAEN-CWU-E

1. QUESTION #1. Do you have historical information on the performance of dams during severe seismic activity?

No historical information exists on the performance of dams in the Central U.S. during large earthquakes primarily because large earthquakes in this area are highly infrequent.

2. QUESTION #2. For those CE dams suspected (via CE studies) of vulnerability due to earthquake induced failure, what downstream counties (or parts of counties) would be affected?

a. Arkansas

Project. Wappapello Lake.

Counties. Clay, Greene, Craighead, Randolph, Lawrence, Jackson, Poinsett, Woodruff.

b. Illinois. N/A.

c. Indiana. N/A.

d. Kentucky. N/A.

e. Missouri

Project. Wappapello Lake.

Counties. Wayne, Bollinger, Butler, Stoddard, Dunklin.

f. Mississippi

(1) Project. *Arkabutla Lake.

Counties. Desoto, Tate, LeFlore, Panola, Quitman, Coahoma, Tunica, Tallahatchie, Grenada, Carroll.

(2) Project. *Sardis Lake.

Counties. Panola, Coahoma, Carroll, Holmes, Sharkey, Quitman, Sunflower, Grenada, Humphreys, Issaquena, Tallahatchie, LeFlore, Yazoo, Washington.

*Assumes Reservoir Water Surface at the flood control pool at failure.

g. Tennessee. N/A.

3. Question #3. What existing data (a listing) is available on contingency plans for CE dams?

CORPS PROJECTS	STATE LOCATION	RIVER	CORPS DISTRICT	INUNDATION MAPS **		CORPS EMERGENCY FLOOD NOTIFICATION PLANS DEVELOPED
				COMPLETED	DATE	
Center Hill	TN	Caney Fork	ORD, Nashville	Yes	FY 83	Yes
Cheatham	TN	Cumberland	ORD, Nashville	No	FY 84	Yes
Cordell Hull	TN	Cumberland	ORD, Nashville	No	FY 84	Yes
J. Percy Priest	TN	Stones	ORD, Nashville	Yes	FY 83	Yes
Old Hickory	TN	Cumberland	ORD, Nashville	No	FY 84	Yes
Dale Hollow	TN	Obey	ORD, Nashville	Yes	FY 83	Yes
Barkley	KY	Cumberland	ORD, Nashville	Yes	FY 83	Yes
Laurel	KY	Laurel	ORD, Nashville	No*	*	Yes
Martins Fork	KY	Martins Fork/Cumberland	ORD, Nashville	Yes	FY 83	Yes
Wolf Creek	KY	Cumberland	ORD, Nashville	Yes	FY 82	Yes
Barren River	KY	Barren	ORD, Louisville	Yes	FY 82	Yes
Buckhorn	KY	Middle Fork/Kentucky	ORD, Louisville	Yes	FY 82	Yes
Carr Fork	KY	North Fork/Kentucky	ORD, Louisville	Yes	FY 82	Yes
Cave Run	KY	Licking	ORD, Louisville	Yes	FY 82	Yes
Green River	KY	Green	ORD, Louisville	Yes	FY 82	Yes
Nolin	KY	Nolin	ORD, Louisville	Yes	FY 82	Yes
Taylorsville	KY	Salt	ORD, Louisville	Yes	FY 82	Yes
Rough River	KY	Rough	ORD, Louisville	Yes	FY 82	Yes
Fishtrap	KY	Levisa Fork/Levisa	ORD, Huntington	Yes	FY 83	No
Dewey	KY	Johns Creek/Levisa	ORD, Huntington	Yes	FY 83	No
Paintsville	KY	Paint Creek/Levisa	ORD, Huntington	Yes	FY 82	Yes
Grayson	KY	Little Sandy	ORD, Huntington	Yes	FY 82	Yes
Brookville	IN	East Fk/Whitewater	ORD, Louisville	Yes	FY 82	Yes
Cagles Mill	IN	Mill Creek/Eel	ORD, Louisville	Yes	FY 82	Yes
C. M. Harden	IN	Raccoon Creek/Mabash	ORD, Louisville	Yes	FY 82	Yes
Huntington	IN	Wabash	ORD, Louisville	Yes	FY 82	Yes
Mississinewa	IN	Mississinewa	ORD, Louisville	Yes	FY 82	Yes

* The entire Laurel pool can be retained by Wolf Creek pool which is the next project downstream--no inundation map is contemplated.

**Inundation map prepared by Corps of Engineers, and date completed or date scheduled for completion.

Monroe	IN	Salt Creek/White	ORD, Louisville	Yes	FY 82	Yes
Patoka	IN	Patoka	ORD, Louisville	Yes	FY 82	Yes
Salamonie	IN	Salamonie	ORD, Louisville	Yes	FY 82	Yes
C. J. Brown	OH	Mad/Miami	ORD, Louisville	Yes	FY 82	Yes
Caesar Creek	OH	Caesar Cr/Little Miami	ORD, Louisville	Yes	FY 82	Yes
W. H. Harsha	OH	East Fork/Little Miami	ORD, Louisville	Yes	FY 82	Yes
West Fork	OH	West Fork/Mill Creek	ORD, Louisville	Yes	FY 82	Yes
Blue Mountain	AR	Tetit Jean	SMD, Little Rock	Yes	FY 83	Yes
Degray	AR	Caddo	LMVD, Vicksburg	No	FY 84	Yes (FY 84)
Lake Ouachita	AR	Ouachita	LMVD, Vicksburg	Yes	FY 84	Yes (FY 84)
Lake Greason	AR	Little Missouri	LMVD, Vicksburg	Yes	FY 84	Yes (FY 84)
Harry S. Truman	MO	Osage	MRD, Kansas City	Yes	FY 81	Yes
Stockton	MO	Sac	MRD, Kansas City	Yes	FY 80	Yes
Smithville	MO	Little Platte	MRD, Kansas City	Yes	FY 81	Yes
Pomme de Terre	MO	Pomme de Terre	MRD, Kansas City	Yes	FY 81	Yes
Long Branch	MO	East Fork, Little Charlton	MRD, Kansas City	Yes	FY 81	Yes
Wappapello	MO	St. Francis	MRD, Kansas City	Yes	FY 82	Yes
Clear Water	MO	Black	LMVD, St. Louis	Yes	FY 82	Yes
Arkabutla	MS	Coldwater	SMD, Little Rock	Yes	FY 82	Yes (FY 84)
Sardis	MS	L. Tallahatchie	LMVD, Vicksburg	Yes	FY 82	Yes (FY 84)
Enid	MS	Yocona	LMVD, Vicksburg	Yes	FY 81	Yes (FY 84)
Grenada	MS	Yalobusha	LMVD, Vicksburg	Yes	FY 82	Yes (FY 84)

4. QUESTION #4. What CE dams can presently be identified as posing the greatest risk of failure during a great earthquake?

<u>PROJECT</u>	<u>STATE</u>	<u>RIVER</u>	<u>CORPS DIVISION/DISTRICT</u>
Sardis	MS	L. Tallahatchie	LMVD, Vicksburg
Arkabutla	MS	Coldwater	LMVD, Vicksburg
Wappapello	MO	St. Francis	LMVD, St. Louis

SUBJECT: Report, "An Assessment of Damages and Casualties for Six Cities in the Central United States Resulting from a Major Earthquake"

1. The subject draft FEMA report has been reviewed and comments are as given below:

a. General. The fragility curve methodology as utilized in this report (i.e. for general estimation of average extent of damages to a large group of a particular type of structure for a given intensity of ground motion) may be useful for disaster response and emergency management planning purposes. However, we consider that a statement should be included within the report to the effect that fragility curves should not be utilized to predict the effects of earthquakes upon any specific structure and that, for this purpose, a comprehensive engineering investigation and analysis is required in order to evaluate many factors which cannot be examined by use of fragility curves.

b. Page 31, Fragility Curve Description. Suggest that the fragility curves which were developed for the 16 types of structures listed on Table II.D.2 be included in the report. In this regard, see para 1(c) below.

c. Page 37, Fragility Curve Development. This paragraph states that a detailed description of the procedures, assumptions, sources of damage data, etc., which were used to develop each fragility curve is given in Appendix A of the report. However, Appendix A was not included in the draft copy of the report reviewed by this office. Inclusion of this information as an appendix in the same volume as the main report would lend credibility to the report findings and would help to make the report a more useful document, particularly to disaster response planners located outside the area of the six subject cities. In addition, suggest that a discussion or description of the data base utilized to develop the fragility curve for each type of structure be included in the report.

d. Page 43, second paragraph. An explanation of the term "damage ratio" which is used in this paragraph would help to clarify this section of the report and several of the tables which follow.

e. Page 57, Damage Assessments for River Ports. Suggest that a statement be included in this section of the report and referred to in the city-specific discussions in Section III that the analyses of availability of port facilities is based on an assumption of a worst-case scenario since adverse soil conditions, such as those described on page 90, do not always prevail at port locations and since some port facilities are designed to resist to a degree many of the adverse effects which can be caused by earthquakes (e.g., excessive settlement) in the course of their usual non-seismic design. Also, recommend that a statement be included in this section of the report that the assumption of earthquake-induced damage to port facilities is not based on specific knowledge of deficiencies in any particular port facility, but was adopted for disaster-response planning purposes.

f. Page 61, third paragraph. This section of the report and several of the sections which follow do not clearly indicate the reason why casualties in wood frame dwellings were based on the number of these dwellings expected to suffer either severe structural damage or collapse while for other types of structures only the expected number of collapses was used. This apparent

inconsistency would seem to unduly inflate the number of casualties to be expected in wood frame structures over those to be expected in other types of structures. Suggest that the basis and justification for the assumption of casualties in both "severe structural damage" and "collapsed" wood frame dwellings be included in the report or that, alternatively, a consistent casualty estimation criteria be applied to all types of structures.

g. Page 62, first paragraph.

(1) Suggest that a detailed explanation for the basis of the casualty rates given in this paragraph and in the paragraphs which follow included in an appendix to this report. This addition should make the report more usable.

(2) Use of the same casualty rate for both collapsed and severely damaged wood frame dwellings does not appear consistent. Suggest this assumption be reevaluated. In this regard, see comment (f) above.

h. Page 62, third paragraph. Clarification is needed in this paragraph as to the reason that night time casualties in hotels were estimated at 5 percent of the daytime casualties since usually the occupancy of a typical hotel increases significantly at night.

i. Page 66, second paragraph.

(1) Suggest that the term "study area" used in the last sentence of this paragraph be restricted to mean the area in and around the six project cities under consideration, rather than the entire area which might be affected by the project earthquake.

(2) Third paragraph. It should be noted that the occurrence of the project earthquake simultaneous with a 10-year flood event is an extremely conservative assumption and that since most of the time little or no water is retained by typical levees in the study area, the amount of flooding resulting from earthquake-induced levee damage would be little or none. It should also be noted that the assumption of damage somewhere along the levees under consideration (without benefit of appropriate site specific engineering investigation and analysis) is also a conservative assumption, since levees in the study area are typically constructed of cohesive materials which are generally resistant to earthquake-induced damage, with the greatest probability of damage or collapse occurring in areas most susceptible to liquefaction. In addition, a breach in a levee system retaining a 100-year flood event would not immediately result in flooding to 100-year levels throughout the area protected by the levee system. In many cases, some amount of warning and evacuation time would exist. Recommend that an explanation of the above facts be included in this section of the report and referred to in the city-specific discussions in part III. We also recommend that a statement be included in this section of the report that the assumption of earthquake-induced damage to levee systems is not based on specific knowledge of deficiencies in any particular levee system, but was adopted for disaster-response planning purposes.

j. Page 78, para III.C.1. The parenthetical expression "(Excluding Those from Dam Failure)" in the title of this paragraph contradicts the statement on page 83 that none of the project cities faces life-threatening risks due to

the failure of dams and levee and that flooding will displace persons but is not likely to produce significant casualties. Suggest this expression be deleted from this paragraph title.

k. Page 83, Failure of Dams and Levees - Human Aspects. This paragraph states that, except for Paducah, none of the cities under study have dams of significance near enough to have an important effect with respect to flooding. It should be noted that studies conducted by the Little Rock District Corps of Engineers have indicated that significant flooding would occur in Poplar Bluff, MO, in the event of a failure of Clearwater Dam which is located about 35 miles NW of Poplar Bluff. However, it should also be noted that other studies completed by the Little Rock District indicate that Clearwater Dam would not experience collapse on substantial damage in the event of an earthquake similar to the one being considered by CUSEPP.

l. Section III, City Specific Discussions. Suggest that a summary table similar to the table included in the executive summary of the beginning of the report be included at the conclusion of each of the six city-specific sections of this section of the report. Such tables would concisely present the predicted effects of the project earthquake in each of the six project cities and would make the report more useful.

m. Page 236.

(1) Second paragraph. Recommend that a statement be included in this paragraph to the effect that the assumption of failure of Kentucky and/or Barkely Dams is not based upon any extensive program of engineering investigations undertaken by this study, but was made merely to facilitate disaster response planning. This paragraph should also state that the studies presently underway by the Corps of Engineers and the Tennessee Valley Authority to evaluate the effects of failure of these dams are being undertaken for essentially the same purpose, i.e., disaster response planning.

(2) Third paragraph. Suggest that the lake level required to produce a flood comparable to the 100-year flood in Paducah, KY, in the event of failure of Barkely or Kentucky Dams be determined and evaluated with respect to the likelihood of occurrence of a pool of that level simultaneous with an earthquake of magnitude similar to the one being considered in this study. Such an evaluation would help to determine whether the assumption of a flood comparable to a 100-year flood at Paducah resulting from a dam break is reasonable for disaster planning purposes.

n. Page 8 was found to be missing from the copy of the report received by this office. In addition, minor corrections have been noted in red on the following pages: 3, 21, 38, 59, 66, 89, 90, 114, 154, 229, 236, 253, 303, and 335.

2. We would like to receive a copy of the finalized report, together with any accompanying appendices, on this portion of the CUSEPP study when the report is published and distributed.



UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

January 27, 1984

Mr. Gary Johnson
Acting Chief, Natural Hazards Division
Office of Natural and Technological
Hazards Programs
Federal Emergency Management Agency
Washington, DC 20472

Dear Mr. Johnson:

I am attaching my review comments on the draft of the report "An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from a Great Earthquake in the New Madrid Seismic Zone" requested by Richard Krimm. I will be attending the 10:00 meeting on January 31 at FEMA to participate in the discussion of the report. I hope we will be able to help in resolving technical issues that might remain following the meeting.

Sincerely,

A handwritten signature in cursive script, reading "Edgar V. Leyendecker".

Edgar V. Leyendecker, Leader
Earthquake Hazards Reduction Group
Structures Division
Center for Building Technology, NEL

Attachment

cc: R. N. Wright, w/att.
C. G. Culver, w/att.

E.V. Leyendecker
January 27, 1984

Preliminary Review Comments for Draft Report Entitled "An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from a Great Earthquake in the New Madrid Seismic Zone"

1. The selection of the study earthquake is outside the scope of this reviewer's expertise. However, once it is selected the rationale should be given and proceed with the study. The report seems almost apologetic about the particular earthquake selected.
2. In general the report offers conclusions and makes statements without a good tie-in as to how the conclusions were reached. As an example, in the Executive Summary the issue of the postulated major earthquake is discussed. It is stated that the conclusions are based upon the postulated earthquake. However, the summary also states "Of perhaps greater importance is the fact that earthquakes of lesser, yet significant, power are much more likely to occur. Such lesser earthquakes would cause wide-spread damage and casualties in at least seven states." Even though the remark is contained in the summary, no supporting data were offered.
3. The various assumptions associated with intensity maps should be clearly stated, whatever those might be.
- * 4. The discussion in Appendix A of the relationship between peak ground acceleration and earthquake intensity should be expanded. This is critical in applying the fragility curve information to the building stock in the intensity map areas. One should not have to go back to the basic reference document in order to dig out how the conversions were obtained. Perhaps the figure missing from my review copy would have provided this information but I suspect that's not the case. Any differences between the central U.S. and West Coast should be noted.
5. An expansion of the text on the data collection procedures is desirable. For example, what proportion of facilities were actually surveyed and what were the checks for accuracy. A better discussion of local codes and practices as varied over time is also desirable. This could include such material as general considerations of seismic design in the geographical area and, if possible, factors such as general construction quality. The latter item might possibly be difficult to discuss.

6. The general principles of using fragility curves to determine probabilities of occurrence for specific damage states are not new. For example, the procedures used in Appendix A of the named report have been used in the evaluation of nuclear facilities. The formulation of the analytical model for the fragility curves does not separate randomness and uncertainty. While the separation might not be possible in the final application, it seems desirable to at least formulate the model on that basis and point out why such separation is not considered feasible before simplifying the problem. Such formulation has been done elsewhere and is not a difficult matter.

7. As used in the report, the fragility curve is defined by two parameters, a measure of the mean strength and a measure of the combination of randomness and uncertainty. The report states that the mean strength values were found based on calculation and combined with engineering judgment. These results were modified using available damage data. This might be the only feasible approach considering the paucity of data available, particularly with regard to structural performance due to an earthquake in the central U.S. However, a better description of how the information was combined is necessary. For example, the report includes tabulations of the results of calculations and the results of damage surveys and the results of combining the two through engineering judgment to arrive at a best estimate of the median capacity for various structural types. This is something of a black box approach and would be difficult for another individual to duplicate. Since judgment is involved it is recognized that duplication of each number might not be possible. However, one should at least be able to follow the logic. Accordingly, it would be helpful to work through an example in the Appendix to show exactly how the numbers were obtained. It is not necessary to do this for all the fragility curves but an example for one would be extremely helpful, particularly if in working through the example the potential sources of error or uncertainty were pointed out. This would also make it easier for the methodology to be applied in other studies.

Page 3

8. A better discussion of the data base used in determining mean resistance and potential sources of error for its application in the central U.S. should be incorporated. For example, the possible errors of using a data base of damaged structures obtained in other areas and applied in the central U.S. should be incorporated.



SAINT LOUIS UNIVERSITY
DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES

3507 LACLEDE AVENUE
SAINT LOUIS, MISSOURI 63103

MAILING ADDRESS:
P.O. BOX 8099 - LACLEDE STATION
SAINT LOUIS, MISSOURI 63156

February 13, 1984

Dr. Samuel W. Speck
Associate Director
State and Local Programs and Support
Federal Emergency Management Agency
Washington, D.C. 20472

Dear Dr. Speck:

I am writing to give my opinion, as you requested, on the final draft of the Allen and Hoshell report "An Assessment of Damage and Casualties for Six Cities of the Central United States Resulting from a Great Earthquake in the New Madrid Seismic Zone".

Let me begin by remarking that the authors of the report did a credible job, consistent with the ground rules they were given at the initiation of the study. In retrospect, those ground rules probably should have been different if the desired end product is an assessment of the hazard potential of the New Madrid seismic zone for the next few generations of people.

Here are some aspects of the ground rules that I am not too happy about now, even though they seemed acceptable two years ago. (This indicates we are making progress in our research.) First, from my recent studies I conclude that in the present or near future the New Madrid seismic zone is capable of producing an earthquake no larger than a 7.6 surface-wave magnitude (M_S), about one unit less than that of the December 16, 1811 earthquake. The latter was used as the "design earthquake" in the Allen and Hoshell report.

Second, when the decision was made to select cities for this study, they were chosen as those which had a Modified Mercalli intensity of VIII or larger on my intensity map of the December 16, 1811 earthquake. Subsequent to that Hopper et al (CUSEPP report 82-3, USGS open-file report 83-179) published an intensity map which took account of local soil conditions and assumed the great earthquake occurred at a point on the fault closest to the town in question. If their map had been used to select cities for the vulnerability study, many more large cities would have had to be added on the criterion of intensity VIII or larger. These include St. Louis, Cincinnati, those lying in the western two-thirds of Kentucky and Tennessee and about the eastern one-half of Missouri, and others. Taking all this into account, the Allen and Hoshell final draft report would greatly underestimate the economic loss and casualties due to the occurrence of a surface-wave magnitude 8.6 earthquake, of which there were three in a two-month time period in the winter of 1811-1812.

Dr. Speck
February 13, 1984
page 2

Third, by restricting cities to those expected to have intensity VIII or greater effects, large metropolitan areas in the intensity VI and VII range are ignored. My studies suggest that the upper level of tall buildings in these regions is going to get a long-duration, sinusoidal-character shaking of relatively large amplitude, capable of doing much damage to the contents of buildings and the inhabitants of them. To take this into account will require looking at cities at least as far away as Chicago, Atlanta, Dallas, Kansas City, etc.

Fourth, the Allen and Hoshell report does not address the consequences of loss of lifelines, such as electric power, natural gas, and communication and transportation facilities on the economy or the lifestyle. I would not be surprised if the economic impact of such secondary features were not greater than the primary effects considered in the draft final report.

In summary, I believe the authors of the Allen and Hoshell report fulfilled the terms of their contract in a satisfactory manner. But I believe that they have not begun to address the total impact of a great earthquake, either in terms of financial loss or casualties or the consequences to the entire United States (they were not asked to do so). If FEMA is more concerned about relatively short-term risk (approximately 50 years) the earthquake magnitude considered for study can be reduced to 7.6 (M_S). Even if this is selected as the "design earthquake", attention ought to be given to damage at large distances and to the secondary disruptive features of the earthquake. Roughly speaking, I would expect an $M_S = 7.6$ earthquake to cause intensities one unit less than those shown on the Hopper et al (1983) map.

Please feel free to call me if some of your questions remain unanswered.

Sincerely yours,

Otto W. Nuttli

Otto W. Nuttli
Reinert Professor in the Sciences

OWN/wf

Dr. Otto W. Nuttli
Professor of Geophysics
Department of Earth and
Atmospheric Sciences
St. Louis University
P.O. Box 8099-Laclede Station
St. Louis, Missouri 63156

APR 17 1984

Dear Dr. Nuttli:

In order to follow-up my earlier acknowledgement of your letter of February 13, 1984, commenting on the final draft of the Allen and Hoshall report, there are several developments of which you should be aware.

We are incorporating your major concern and expect to modify the Allen and Hoshall report to reflect a magnitude 7.6 event in addition to the 8.6 event. Of course this study was never intended to be a regional vulnerability assessment and the assessment of damage and casualties will continue to be confined to the six cities originally selected.

With regard to the Central U.S. Earthquake Preparedness Project (CUSEPP) in general, we are continuing the vulnerability assessment with an effort in the City of St. Louis and its surrounding three most populous counties. Prior to expanding the vulnerability assessment into other regions of the CUSEPP planning area, we are evaluating methodologies to assure that they can account for secondary impacts, rural versus urban characteristics, and data collection burden concerns. We shall also begin activities aimed at defining the affects of a New Madrid seismic event on tall buildings in distant cities.

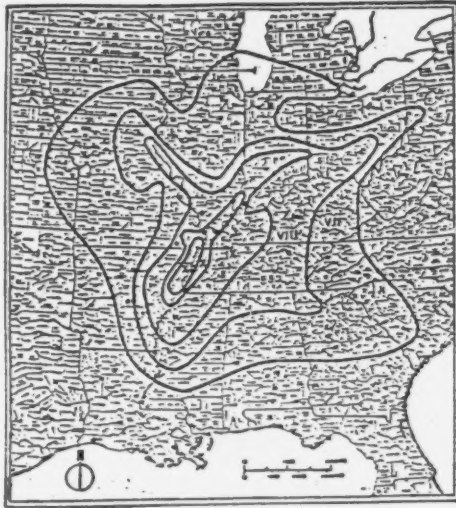
We appreciate your time and efforts in the Central U.S. Earthquake Preparedness Project. I look forward to seeing you in St. Louis at the National Earthquake Conference.

Sincerely,

SIGNED

Samuel W. Speck
Associate Director
State and Local Programs
and Support

AN ASSESSMENT OF DAMAGE
AND CASUALTIES FOR SIX CITIES
IN THE CENTRAL UNITED STATES
RESULTING FROM A GREAT EARTHQUAKE
IN THE NEW MADRID SEISMIC ZONE



**CENTRAL UNITED STATES
EARTHQUAKE PREPAREDNESS PROJECT
(CUSEPP)**

CUSEPP REPORT NUMBER

REVIEW DRAFT

CENTRAL UNITED STATES EARTHQUAKE PREPAREDNESS PROJECT
(CUSEPP)

AN ASSESSMENT OF DAMAGE AND CASUALTIES
FOR SIX CITIES IN THE CENTRAL
UNITED STATES RESULTING FROM A
GREAT EARTHQUAKE IN THE NEW MADRID SEISMIC ZONE

REVIEW DRAFT

By
Allen & Hoshall, Inc.
2430 Poplar Avenue
Memphis, TN 38112

Prepared for the
FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

CUSEPP Number 83-XXX

This report is preliminary and has not been edited or reviewed for final distribution.

EXECUTIVE SUMMARY

The Central United States Earthquake Preparedness Project (CUSEPP) is an on-going effort of the Federal Emergency Management Agency (FEMA) to determine the potential consequences of a major earthquake in the New Madrid Seismic Zone, to increase the awareness of those consequences among public officials and the private sector and to plan for coping with them or, where possible, avoiding them. This report, supported by information developed in two preceding CUSEPP studies, estimates the potential consequences of a major earthquake in six cities within or near the seismic zone. These cities are: Memphis, Tennessee; Little Rock, Arkansas; Evansville, Indiana; Paducah, Kentucky; Carbondale, Illinois; and Poplar Bluff, Missouri.

The postulated major earthquake would have a magnitude of 8.6 on the Richter scale. The selection of this large seismic event for CUSEPP planning is reasonable from at least two points of view. First, such earthquakes have actually occurred in this region; each of the three "great" earthquakes of 1811 and 1812, which resulted in the formation of Reelfoot Lake and are widely referenced in the literature, was approximately the size of the postulated earthquake. Second, recent seismic investigations have shown that such an earthquake has a real, though small, probability of occurring during the life span of existing and planned structures and the lifetime of persons now living. Of perhaps greater importance is the fact that earthquakes of lesser, yet significant, power are much more likely to occur. Such lesser earthquakes would cause widespread damage and casualties in at least seven states. The occurrence of the major CUSEPP planning earthquake would result in disruption, death, and injury on a scale seldom if ever experienced in

the history of this nation; the immediate and long relief and recovery efforts would place a significant and prolonged burden on the regional as well as the national economy. The selection of the postulated event is appropriate to encompass the full measure of consequences for which response planning should be carried out.

The serious (though localized) damage in Coalinga, California which resulted from the May 2, 1983 event, demonstrates the damage which can be caused by a moderate earthquake (Richter 6.5 or Modified Mercalli Intensity IX). Otto Nuttli, of Saint Louis University, in CUSEPP Report 81-1, indicated that the New Madrid Fault presently has enough stored energy to produce an earthquake of at least that magnitude. However, because of the different soil conditions and the general lack of adequate seismic design in structures in the Mississippi Valley region, a New Madrid quake could be expected to cause much more extensive damage than would result from an event of similar magnitude in California.

To estimate the probable effects of the postulated CUSEPP earthquake in the New Madrid Fault Zone on the six cities, the following procedures were employed. Structural inventory and critical facilities data were collected by FEMA and supplemented in some cases by further investigations of the project team. Estimates of ground shaking in the six cities were provided by USGS in CUSEPP's report 82-3. On the Modified Mercalli Intensity scale, these ranged between VI and X. To estimate structural damage, a series of fragility curves, which describe the probability of structural failure as a function of level of ground shaking, were developed for the sixteen different types of structures of interest, which included buildings, utility plants and systems, dams, bridges and tanks. These fragility curves were applied to the

structures specified in the inventory data, usually grouped according to a function, to determine the expected damages at the ground shaking intensities specified for the structures possessive location. Casualty estimates were based on the expected number of occupants of the buildings which would survive collapse or, in some cases, severe structural damage. Average building occupancies were derived from census data, employment data and the FEMA inventory data.

Should the CUSEPP planning earthquake occur, the six project cities would suffer varying effects. Table ES-1 summarizes some of the major consequences which would result from an occurrence of the postulated seismic event. Following is a discussion of these and other probable consequences.

Casualties

The number of casualties caused by the planning earthquake would depend on the time of day at which it occurred. At night, most of the population is found in relatively safe wood frame residential structures, but during a typical working day the majority of the population moves to buildings which are much more vulnerable to severe structural damage or collapse. A substantial proportion of the daytime casualties would occur among school children. Total daytime deaths in the six cities could easily exceed 3,000, as shown in the following summary:

City	Total Deaths		100,000 Population		School Deaths as % of Total Day Deaths
	Night	Day	Night	Day	
Memphis	359	2,544	56	395	23
Paducah	50	117	119	279	18
Carbondale	10	83	31	261	45
Evansville	29	222	22	163	30
Poplar Bluff	3	19	17	109	78
Little Rock	3	61	2	34	11
Total	454	3,046	250	1,240	25

Medical Services

Medical services in the six cities would probably be unable to provide adequate care for all the injured, except perhaps in Little Rock, without outside assistance. Health care professionals may encounter difficulty reaching their places of work, and a few (less than two percent) would be among the dead and injured. Because of severely damaged or collapsed hospital structures, the normal availability of beds and medical supplies would be reduced.

Memphis would be the most severely affected:

City	Hospital Structures Surveyed	Hospital Beds Expected to be Available	
		Number	% of Total
Memphis	25	2,770	49
Paducah	7	720	89
Evansville	20	2,030	90
Poplar Bluff	7	690	90
Carbondale	6	190	94
Little Rock	13	3,760	100
Total	78	10,160	75

Most of the cities would not have sufficient surviving beds to accommodate the injured in addition to their normal load of patients. Other services would be similarly affected. The number of seriously injured persons requiring prompt medical attention would be about four times the number of deaths in each city. Additional casualties could also result from fires and flooding. STOPPED HERE.

Transportation Systems

Damage to transportation systems would seriously hamper rescue and relief efforts and would have a long-term disruptive effect upon regional and national commerce. Highway access to Memphis as well as major highway availability within the city would be severely limited. The most probably surviving access route would be U.S. 72 from the east; bridge collapses would either cut or block most, but probably not all, of the eight other principal arteries into the city. Poplar Bluff would be liable to lose highway access from the east. Paducah's highways would suffer some damage, but no serious loss of accessibility would result. Little loss of accessibility would occur in Carbondale and Evansville, and almost no serious highway damage would take place in Little Rock.

Damages to railway networks would follow a pattern similar to the highway damages. Little Rock would probably suffer no loss in rail accessibility; Evansville would experience little or none. Carbondale could suffer impaired accessibility from the west, which Paducah is most vulnerable to rail losses to the north (crossing the Ohio River) and from the east. The cities likely to suffer greatest disruption are Poplar Bluff and Memphis. Rail access from all directions into Poplar Bluff would be at risk of serious impairment, though not to the extent expected in Memphis, where over 75% of all system sections have relatively low survival probabilities, and all sections entering the city but one are at risk.

The above assessments are based on the probabilities that highway and railway structures would collapse. Many more structures might not collapse but would suffer severe damages that would restrict or prevent

their use by heavy vehicles. In particular, all railway traffic would be stopped for at least 24 to 48 hours, or for as long as required to inspect all structures in each line segment. For that reason, the most immediate transportation needs into and out of the six cities would have to be met via highway and air transport.

River port facilities are expected to be extensively disrupted, with the minimum disruption occurring in Little Rock. The cities of Carbondale and Poplar Bluff do not possess river port facilities and thus would not be significantly affected in this manner. Memphis, Evansville and Paducah are expected to sustain substantial damage to their river ports thus limiting the usefulness of these facilities in relief efforts.

Partial or limited availability of airport facilities is expected following the project earthquake. Those facilities at airports which rely on electrical power, i.e., navigation aids and runway lighting, may be out of commission for some period of time, even if emergency power is available. Runways may be available, at least for limited use, even in severely effected areas. Runways may sustain damage but still be capable of allowing landings and takeoffs of aircraft bearing vital supplies. The loss of navigation and landing aids can be significant especially during winter when weather conditions are frequently marginal or below landing minimums. Utility Systems

Project cities are expected to experience serious impairment or loss of their four main utility systems (electric, water, gas, and sewers). Little Rock may not lose availability of all systems; those which are out-of-service are likely to be restored relatively quickly. Systems in other cities will be unavailable for periods from days to months. The most essential and, unfortunately, the most "fragile" of the utility networks are the electric power systems. So many things depend upon the availability of electric power that even its short term

loss, under normal conditions, is a major setback to a community. To superimpose a loss of electric power upon a severe and widespread disaster may mean: no water to fight fires or for drinking, no light or heat, no communications, no sewage pumps, etc. Improving the survivability of electric utilities should be a high priority undertaking in the region's immediate future. The following summary presents the estimated availability of utility systems for the six project cities:

<u>City</u>	<u>Electric</u>	<u>Water</u>	<u>Gas</u>	<u>Sewer</u>
Memphis	U	U	U	M*
Little Rock	U*	A	M*	A
Evansville	U	U	U	U
Paducah	U	U	U	U
Carbondale	U	U	U	U
Poplar Bluff	U	U	U	U

- U - System likely to be unavailable.
M - System may be available.
A - System likely to be available.
* - Limited and/or modified use possible.

Flooding

Were the earthquake to occur at a time when high water conditions existed in the area's rivers and streams, flooding of low-lying areas, protected by levees, is likely to occur. This is because levees are expected to be damaged sufficiently to allow flooding behind them. Earthen dams in the area, however, are not expected to be damaged to the

extent that they will lose their reservoirs. This finding, combined with the situation that low or flood-prone areas in the project cities are mostly undeveloped and unoccupied, indicates that no significant casualties would be expected due to flooding following the CUSEPP planning earthquake. Flooding would, however, result in displaced persons and would hamper relief efforts.

Fires

Giant fires, or conflagrations, involving major portions of a city are unlikely, due to the nature and density of construction in the project cities. Widespread individual or small-group structural fires are likely, however, due to miscellaneous damage-related factors.

Shelter Requirements

Many individuals will require shelter due to their dwellings being rendered uninhabitable by actual earthquake-caused damage, flooding and other causes. These persons may find alternative shelter in surviving, relatively undamaged structures (following inspections). Surviving schools are particularly good candidates for such shelter. The following is a listing of the estimated requiring numbers of persons requiring shelter in the six project cities:

City	Persons Likely to Require Shelter	
	Due to Flooding	Due to Damage to Residence
Memphis	1,199	231,680
Little Rock	4,707	2,440
Evansville	17,497	11,095
Paducah	5,254	13,318
Carbondale	----	5,728
Poplar Bluff	----	5,743
Totals	28,657	270,004

Restoration/Replacement Costs

The financial and economic burden placed upon the region and the entire nation by an occurrence of such a disaster would be very great. The following summarizes such costs for the project cities.

Restoration/Replacement Costs (Millions of Dollars)			
<u>City</u>	<u>Structures</u>	<u>Utilities</u>	<u>Total</u>
Memphis	\$22,095	\$2,908	\$25,003
Little Rock	\$ 1,463	\$ 454	\$ 1,917
Evansville	\$ 4,781	\$ 360	\$ 5,141
Paducah	\$ 3,002	\$1,395	\$ 4,397
Carbondale	\$ 809	\$ 257	\$ 1,066
Poplar Bluff	\$ 558	\$ 125	\$ 693
Total (Millions of Dollars)			\$38,217

Summary

In summary, the occurrence of the project earthquake within the study area would cause massive and widespread disruption, damage, and casualties. Remaining resources within the affected region would be unable to adequately provide for the emergency response needs of these communities. Only with very large scale outside support and assistance of all kinds could further loss of life, suffering and disruption to regional lifelines be reduced. It is with this in mind that the damage and casualty estimates produced by this project are to be used. It is hoped that the information contained within this report will be a meaningful step toward the development of appropriate national, regional and local response plans, and longer range strategies.

REVIEW DRAFT

FOR

EMERGENCY RESPONSE PLANNING

PURPOSES

ONLY

The primary purpose of this report is to assist National and regional emergency managers and planners in the development of response plans to deal with the consequences of a major earthquake in the central United States. This report is not intended for any other use.

In particular, the probabilistic methods which underlie the estimation of damage to structures and the resulting casualties, were developed and applied to yield such estimates only for groupings or aggregations of structures of similar type or purpose. For the level of analysis performed for this report, these techniques were not intended to provide damage descriptions for individual structures. No attempt should be made to use the findings of this report for other than the above stated purpose.

REVIEW DRAFT

ACKNOWLEDGEMENTS

- * Allen & Hoshall, Inc., Memphis, Tennessee, was responsible for overall preparation of this report.
- * SYSTAN, Inc., of Los Altos, California, was responsible for casualty estimation and damage assessments for transportation systems.
- * Jack R. Benjamin and Associates, of Mountain View, California, was responsible for the development of fragility curves and for guidance in their application.

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TABLE OF CONTENTS

	<u>Page</u>
<u>Executive Summary</u>	Preceding Table of Contents
<u>I. INTRODUCTION</u>	
A. Project Purpose, Scope and History	
B. Methodology Overview	
C. Description of Study Area	
Seismic Factors	
D. Earthquake Fundamentals	
<u>II. METHODOLOGY</u>	
A. Introduction and General Approach	
B. Collection of Base Data Inventories	
C. Estimates of Ground Shaking and Soils Behavior	
D. Damage Assessment	
1. General	
2. Fragility Curve Methodology	
3. Damage to Transportation System	
4. Damage to Utilities	
5. River Ports; Airports	
E. Methods of Estimation for Casualties and Other Effects on Population	
1. General	
2. Casualty Estimation	
3. Dam and Levee Failure	
4. Displaced Persons and Available Shelter	
5. Large Fires/Conflagrations	
<u>III. EFFECTS UPON SIX PROJECT CITIES</u>	
A. Introduction	
B. General Discussions	
1. Effects on Medical Resources and Facilities	
a. Major Hospitals	
b. Health Manpower	
c. Blood Banks	
d. Clinical Labs	
e. Ambulance	
2. Casualties: Demands on Medical Resources	
a. From Structural Failure	
b. Displaced Persons and Available Shelter	
3. Effects on Critical Facilities	
a. Public Services and Structures	
1. Fire Service	
2. Police	

- 3. Schools
 - b. Communication
 - c. Transportation
 - 1. Rail
 - 2. Highway
 - 3. Dock
 - 4. Airport
 - d. Public Utilities
 - 1. Electric
 - 2. Water
 - 3. Natural Gas
 - 4. Sewage
- C. Memphis
- 1. City Description, General Information
 - 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower
 - c. Blood Banks
 - d. Clinical Labs
 - e. Ambulances
 - 3. Casualties: Demands on Medical Resources
 - a. Casualties from Structural Failure
 - b. Displaced Persons and Available Shelter
 - 4. Effects on Critical Facilities
 - a. Public Services and Structures
 - 1. Fire Service
 - 2. Police
 - 3. Schools
 - b. Communications
 - c. Transportation
 - 1. Rail
 - 2. Highway
 - 3. Dock
 - 4. Airport
 - d. Public Utilities
 - 1. Electric
 - 2. Water
 - 3. Natural Gas
 - 4. Sewage
 - e. Conflagrations
- D. Little Rock
- 1. City Description, General Information
 - 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower
 - c. Blood Banks
 - d. Clinical Labs
 - e. Ambulances
 - 3. Casualties: Demands on Medical Resources
 - a. Casualties from Structural Failure
 - b. Displaced Persons and Available Shelter

4. Effects on Critical Facilities
 - a. Public Services and Structures
 1. Fire Service
 2. Police
 3. Schools
 - b. Communications
 - c. Transportation
 1. Rail
 2. Highway
 3. Dock
 4. Airport
 - d. Public Utilities
 1. Electric
 2. Water
 3. Natural Gas
 4. Sewage
 - e. Conflagrations
- E. Evansville
 1. City Description, General Information
 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower
 - c. Blood Banks
 - d. Clinical Labs
 - e. Ambulances
 3. Casualties: Demands on Medical Resources
 - a. Casualties from Structural Failure
 - b. Displaced Persons and Available Shelter
 4. Effects on Critical Facilities
 - a. Public Services and Structures
 1. Fire Service
 2. Police
 3. Schools
 - b. Communication
 - c. Transportation
 1. Rail
 2. Highway
 3. Dock
 4. Airport
 - d. Public Utilities
 1. Electric
 2. Water
 3. Natural Gas
 4. Sewage
 - e. Conflagrations
- F. Paducah
 1. City Description, General Information
 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower
 - c. Blood Banks
 - d. Clinical Labs
 - e. Ambulances

- 3. Casualties: Demands on Medical Resources
 - a. Casualties from Structural Failure
 - b. Displaced Persons and Available Shelter
- 4. Effects on Critical Facilities
 - a. Public Services and Structures
 - 1. Fire Service
 - 2. Police
 - 3. Schools
 - b. Communications
 - c. Transportation
 - 1. Rail
 - 2. Highway
 - 3. Dock
 - 4. Airport
 - d. Public Utilities
 - 1. Electric
 - 2. Water
 - 3. Natural Gas
 - 4. Sewage
 - e. Conflagrations
- H. Carbondale
 - 1. City Description, General Information
 - 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower
 - c. Blood Banks
 - d. Clinical Labs
 - e. Ambulances
 - 3. Casualties: Demands on Medical Resources
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 - b. Displaced Persons and Available Shelter
 - 4. Effects on Critical Facilities
 - a. Public Services and Structures
 - 1. Fire Service
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 - 1. Electric
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- I. Poplar Bluff
 - 1. City Description, General Information
 - 2. Effects on Medical Resources and Facilities
 - a. Major Hospitals
 - b. Health Manpower

- c. Blood Banks
- d. Clinical Labs
- e. Ambulances
- 3. Casualties: Demands on Medical Resources
 - a. Casualties from Structural Failure
 - b. Displaced Persons and Available Shelter
- 4. Effects on Critical Facilities
 - a. Public Services and Structures
 - 1. Fire Service
 - 2. Police
 - 3. Schools
 - b. Communications
 - c. Transportation
 - 1. Rail
 - 2. Highway
 - 3. Dock
 - 4. Airport
 - d. Public Utilities
 - 1. Electric
 - 2. Water
 - 3. Natural Gas
 - 4. Sewage
 - e. Conflagrations

IV. ESTIMATES OF RESTORATION/REPLACEMENT COSTS

LIST OF TABLES

TablePage

LIST OF FIGURES

FigurePage

I. INTRODUCTION AND GENERAL APPROACH

A. Report Format and Organization

The material contained in this report can be divided into two major areas. The first, Sections I and II, describes the overall project and its methodology. The second, Section III, is a presentation of the project's findings and consists of an initial general section which contains discussions of each results category, and which also presents findings and conclusions pertaining to all or most project cities collectively. Then follow the six sub-sections presenting and discussing the findings for each project city. A summary and recommendations section (Section IV) and bibliography conclude the report.

B. Project Purpose, Scope and History

The purpose of this project, as reflected in the title, is to assess the effects of a major or great earthquake upon six cities in the central United States. These are: Memphis, Tennessee, Little Rock, Arkansas, Paducah, Kentucky, Evansville, Indiana, Carbondale, Illinois, Poplar Bluff, Missouri. These cities represent the most populous cities in the six states effected by the New Madrid zone, selected for their proximity to the New Madrid Fault zone. This report is part of the ongoing Central United States Earthquake Preparedness Project (CUSEPP), which has come into existence due to a growing awareness on the part of seismic experts and emergency managers and planners of the risk involved with the occurrence of a significant earthquake event along the New Madrid Fault. Two other CUSEPP documents have preceded this report and contain information which is preparatory to it. These reports will be referenced throughout this report and contain

considerable relevant background information. The first, CUSEPP Report (Nottingham, 1981) No. 81-1 is titled "Evaluation of Past Studies and Identification of Needed Studies of the Effects of Major Earthquakes Occurring in the New Madrid Fault Zone". The second report, (Hopper, et al, 1983) is titled "Estimation of Earthquake Effects Associated with a Great Earthquake in the New Madrid Seismic Zone". This report is CUSEPP No. 82-3.

The Six City Report presents the results of the application of prototype procedures for data collection and manipulation, estimation of damage and casualties, and assessments of disruption of essential services and systems due to the effect of a hypothetical planning or "project" earthquake. This "project" earthquake, as discussed in the CUSEPP reports mentioned above, is the hypothetical reoccurrence of a major or "great" earthquake, equivalent in magnitude to one of the three 1811-1812 events, occurring anywhere along the New Madrid Fault.

This report can serve at least two purposes. It is intended to assist emergency managers and planners at all levels in the initiation of awareness, preparedness and response plans for the six project cities and the region in general. More importantly, it should be of great significance and benefit to regional and national planners who seek to define the multiple overall effects of damaging earthquakes in this region. It also serves as a test and trial of new methodologies which can be applied to perform similar surveys for all of the area anticipated to be effected by such a project earthquake and not only for the six urban areas.

Methodology Overview

The overall approach or methodology used for this study was to first acknowledge and define the seismic risk to which this region is exposed. This has been done in the two previously mentioned CUSEPP

project reports. The first, report No. 81-1, describes the history of the New Madrid Fault System and the likelihood of this seismic zone producing damaging earthquakes in the future, and makes recommendations as to appropriate planning and investigation activities. This report concludes that the fault system is definitely capable of producing disastrous earthquakes now and in the foreseeable future and therefore urges that appropriate planning start immediately. General estimates are made of the extent and nature of damage which was caused by one of the three great earthquakes of 1811 and 1812, and the type of immediate relief required by the various disaster zones which would result from a recurrence of such an event in modern times.

The second document, CUSEPP report No. 82-3, also begins with a historical review of the events of 1811 and 1812, giving a more detailed examination of the known effects of these events upon the six project cities. The main contributions of this report are to specifically delineate the levels of ground shaking to be expected in the affected regions of the central United States of ground shaking. These levels are expressed in terms of the Modified Mercalli Intensity (MMI) scale; intensities VII through XII were predicted to occur in the various project cities. Soil's failure, loss of bearing capacity and liquifaction in the project cities is also addressed. These predictions of ground shaking within the six project cities were a major and fundamental element required by this project; they will be discussed further in Section II, which addresses project methodology in greater detail.

The next major methodology step was to describe the structures and services within the project cities by assembling a body of information

of sufficient detail and extent to allow estimates of damage to them to be made, presuming they were exposed to the predicted ground shaking levels previously discussed. To do this required a massive effort on the part of FEMA staff, ~~the~~ ^{local government and private} volunteers in the six project cities. This large body of detailed information was augmented and expanded by the project analysis team. The major feature of this information was that it described, using a variety of appropriate methods, the structural systems and construction methods utilized for virtually every structure of interest within the limits of the project cities. This included all buildings, i.e., residential and non-residential, and "critical facilities" a grouping which encompasses many structures kinds and uses of, such as bridges, pumping and electrical substations, as well as certain special building types, such as hospitals and schools. An equally important data element, assembled from many sources, was the numbers of people occupying buildings within the project cities. Additional information was collected for critical city services, notably utility, communications and transportation systems. This detailed and extensive data compilation,, coupled with the ground shaking estimates previously described, were the basic inputs to the methodologies used to estimate damage, casualties and disruption to - and availability of - services and systems. Further discussion of the structural information data base will be presented in Section II, Methodology.

Description of Study Area Seismic Factors

The region of the United States which comprises this project study area includes that portion of the United States which has been determined to be seriously effected in the event of an occurrence of a major or great earthquake. The study area surrounds the presumed location of the New Madrid Fault Zone, and generally encompasses that area, near the fault, which is expected to experience ground shaking and resulting damage equal to or greater than that described by a ground shaking intensity of Modified Mercalli VIII. In descriptive terms, this region includes southern Illinois, southwestern Indiana near the Ohio River, western Kentucky, the Missouri ~~Bootheel~~ and southeastern Missouri Ozark region, central and eastern Arkansas, west Tennessee, and nearby portions of northwest Mississippi. Generally speaking this region encompasses a very large zone of the central United States within the central and lower Mississippi Valleys.

As referenced in the previously mentioned CUSEPP reports 81-1 and 82-3, the activity of the New Madrid Fault Zone has received increasing interest and attention on the part of seismic experts and emergency planners. CUSEPP reports 81-1 and 82-3 provide excellent descriptions of the seismic history and forecasts of potential future activity. Thus no attempt will be made in this report to duplicate descriptions contained in reports 81-1 and 82-3. A brief overview of the seismic situation is presented here to familiarize the reader with overall conditions. The reader is also referred to the glossary of seismic and earthquake terminology and the short discussion of earthquake basics found in Part E of this section. This material will aid those not familiar with seismic terminology and will hopefully provide enough

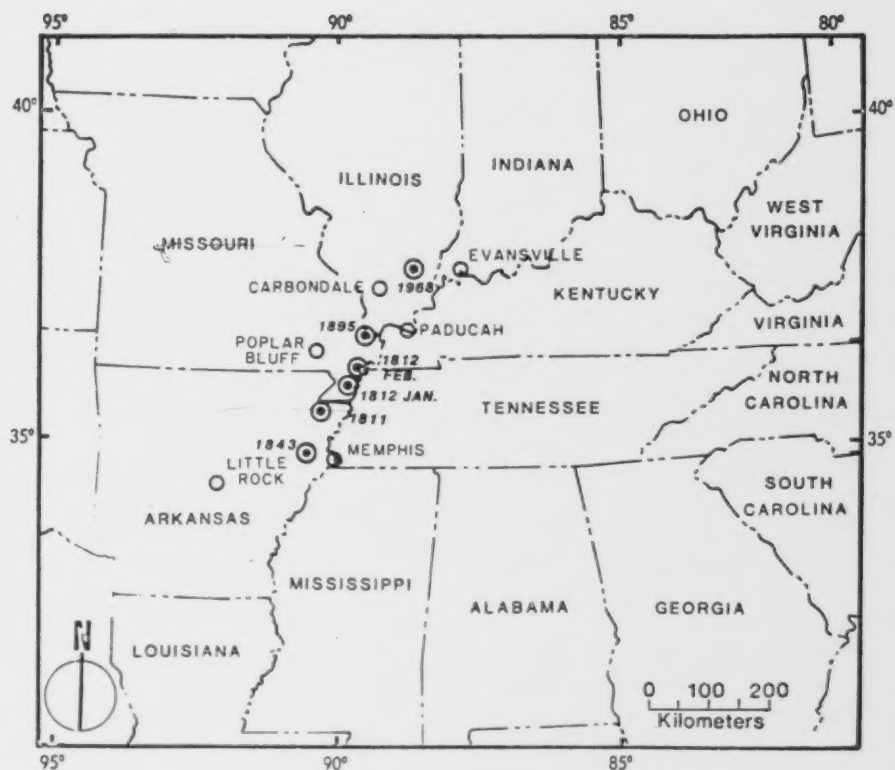


Figure 1. Map showing the six cities evaluated in this report. Also shown (circles with dots) are localities of the epicenters of the large historical earthquakes discussed in this report.

descriptive information to allow for clear understanding of the background material and results of this report.

In the past, when referring to earthquakes within the United States, most attention and recognition has been and continues to be focused on past earthquakes which have occurred in relatively recent time along the west coast and the earthquake planning activities regarding earthquakes in that region. However, the New Madrid Fault system produced, in 1811 and 1812, a series of three great earthquakes which are among the largest known in the United States and indeed in the world. These events have until recently been viewed by residents of the area and by the nation in general as curiosities or isolated events which have no potential of repetition. This attitude has undoubtedly come to pass due to the timing of these major earthquakes; i.e., they occurred early in our nation's history when the region was very sparsely populated, the events were experienced by relatively few individuals, the events were reported in a sparse and sporadic manner, and were treated in the time span following the events in the same manner as Indian legends or other pioneer tales. Since 1811 and 1812 no repetition of such a massive earthquake has occurred, although the fault has produced several earthquakes of moderate to strong intensity. Although interest in the events of 1811 and 1812 and in the seismicity involved in the New Madrid Fault Zone has persisted from one individual researcher to another over the intervening time period, it has been under relatively recent conditions of improved scientific knowledge and instrumentation that a better and clearer understanding of this fault system has emerged. As referenced in the CUSEPP reports 81-1 and 82-3

and the other references listed in the bibliography, it is now known that this fault system is definitely active and is associated with hundreds of small (generally too small to be felt) earthquakes each year. The locations or epicenters of these small seismic events have been made possible by networks of modern seismigraphic equipment, primarily those established by St. Louis University, St. Louis, Missouri and Memphis State University, Memphis, Tennessee. Data from these instruments have enabled scientists to learn a great deal about the nature and behavior, both current and future, of this fault system. The results of these studies strongly indicate that damaging earthquakes are to be expected within the lifetimes of people and structures in existence today, and that a reoccurrence of a "great" earthquake with a strength equivalent to those events of 1811 and 1812 is also possible, though with a lower probability during the life spans of people and structures now in existence. Users of this report and those which preceded it should take appropriate note of these findings. Among these is the situation that, due to the geologic formations which lie beneath the central portion of the United States, i.e., that region of the United States generally east of the Rocky Mountains, the effects of a significant earthquake will be felt over a much greater area than those which will occur in California. Two points of example are presented here as verification of this phenomena. The first is that the events of 1811 and 1812 produced ground shaking that was detectable from the Canadian boarder of the United States to the Gulf of Mexico and from the Great Plains to the Atlantic Coast. Smaller, but nonetheless significantly large, areas of ground shaking have been associated with the lesser earthquakes which have occurred along the New Madrid Fault

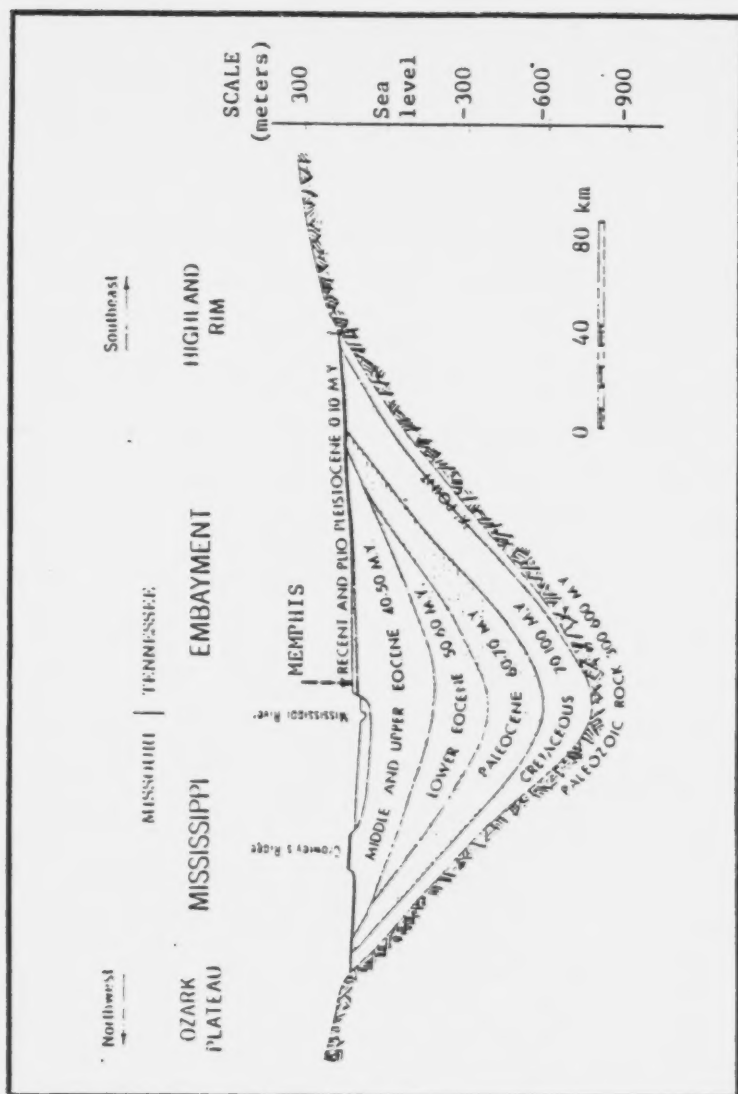


FIG. 3-2, Diagrammatic cross-section of the Mississippi Embayment

(after Stearns and Wilson, 1972)

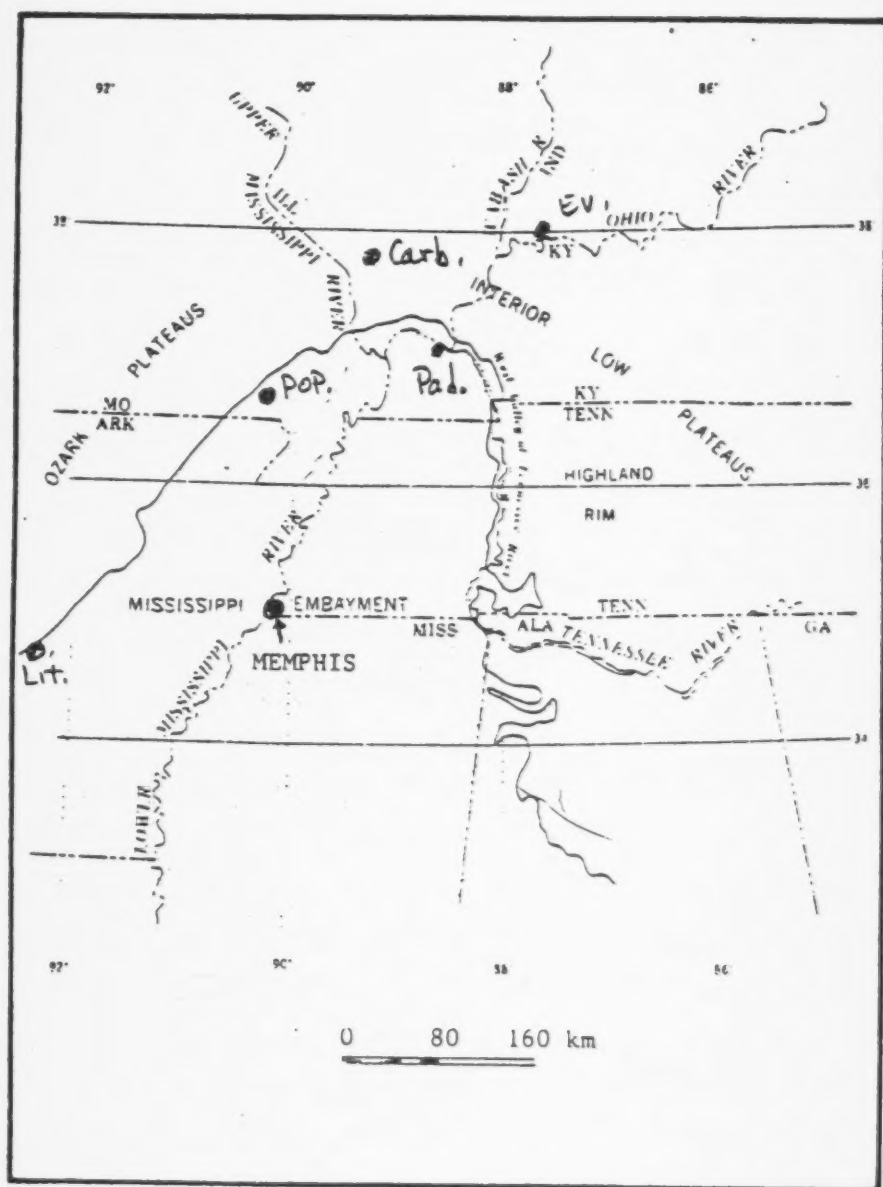


FIG. 3-1, Major geologic provinces

(after Stearns and Wilson, 1972)

since 1811 and 1812. This has led seismic experts to produce the isoseismal patterns for this project's hypothetical or planning earthquake which are depicted in Figure _____. This depiction of ground shaking intensities, expressed as Modified Mercalli Intensities, should be studied and reviewed closely. Doing so will reveal the great extent of serious damage which is to be expected with the project earthquake. (i.e., a reoccurrence of one of the 1811 and 1812 events.) When the extent and nature of the expected damage is reviewed, it becomes apparent that such an earthquake, should it occur, would produce such wide spread destruction that the resulting catastrophe would be the greatest natural disaster ever known or experienced in this country. Responding to the emergency needs of this region immediately following the disaster and assisting the region in post quake recovery would tax the very fiber of the entire nation. The damage to both people and property would be on the level of general warfare, as would the economic and material burdens placed upon the nation to affect a recovery. Although a maximum-level type event such as represented by the hypothetical project earthquake has a low probability of occurring in the near future, it is wise to choose such an event for planning purposes. Doing so allows for appropriate scaling of effort and resources. And it allows the more likely lesser events, which definitely have potential for wide-spread damage and disruption, to be dealt with in a better perspective for response and recovery. A great many of the effects upon these six cities, which are described, predicted and estimated in this report, would occur to a similar extent with a less severe earthquake than the one selected for this project. This is especially true with respect to damage to certain aspects of electrical utility systems and other

utility networks as well.

In summary, an assessment of the seismic status of the central United States, based on current knowledge of the New Madrid Seismic Zone, is that a real potential for serious and damaging earthquakes definitely exists within a time frame which mandates planning activities by all effected levels of our society. This report presents the predicted consequences of a maximum-level event (examples of which have occurred in historic times) in terms of numbers of casualties and disruption to vital urban systems in six selected cities of various sizes and various distances from the seismic zone. These estimations will allow planners at all levels to begin to estimate and provide for resources needed to cope with such a disaster (and with lesser but nonetheless serious ones) and to begin strategic planning and development of steps needed to affect a recovery.

Earthquake Fundamentals

The following material has been excerpted from Engineering Aspects of the 1971 San Fernando Earthquake, U. S. Department of Commerce, December, 1971, and is intended to present basic information concerning earthquakes and seismic terminology.

Earthquake Terminology

There are two terms which are commonly used to describe the size of an earthquake. These are "intensity" and "magnitude". These two terms are often confused, and it is important to understand the difference.

INTENSITY is an indication of an earthquake's apparent severity at a specific location, as determined by observers. It is a measure of the effects of an earthquake determined through interviews with persons in the quake-stricken area, damage surveys, and studies of earth movement.

The Modified Mercalli Intensity used in the United States grades observed effects into twelve classes ranging from I to XII. Description of this scale is given in Table _____. The older Rossi-Forel Intensity scale has ten categories of observed effects, and is still used in Europe. Still other intensity scales are in use in Japan and the U.S.S.R.

The potential severity of the earthquake at a particular location can also be determined from the records of a strong motion seismometer (accelerometer) mounted on a rigid foundation. The readings from such instruments indicate the amplitude and frequency of earth accelerations at that specific site and can be integrated to determine both velocities and displacement. Such information can be used by engineers in determining the degree of motion to which structures have been subjected and to make determinations of the forces which are exerted on

structures. The measure of potential severity of the earthquake at the recording station is usually expressed as a fraction of the acceleration due to gravity.

MAGNITUDE, on the other hand, expresses the total amount of energy released by an earthquake as determined by measuring the amplitudes produced on standardized recording instruments. Thus, it is a measure of the absolute size or strength of an earthquake and does not consider the effect at any specific location.

The Richter scale, which gives the numerical value of the magnitude, was defined by Richter in 1935 as logarithms (base 10) of the amplitude in microns of the trace written by a seismograph at a distance of 100 km from the epicenter.

Observations at distances other than 100 km can be corrected to convert them to the standard distance. Because the Richter Scale is expressed in logarithms of base 10, a unit increase in the scale is equivalent to a ten fold increase in the real trace magnitude. For example, an earthquake of magnitude 8 represents a seismograph amplitude 10 times greater than that of a magnitude 7 earthquake, 100 times greater than that of a magnitude 6 earthquake, and so on. There is no upper limit to the Richter scale. The largest magnitude ever recorded is 8.9.

Magnitude-Intensity-Relations

Magnitude and maximum intensity of an earthquake are interdependent to some degree, but there is no close correlation between them. For example, an earthquake might have a low magnitude but because of shallow focus, poor soil condition, or poor building construction practice, it might cause a great deal of damage; thus, it would have a very high

intensity. On the other hand, an earthquake of very large magnitude might have a great focal depth, or might occur in an area where there is very little man-made structure to damage. It would not, therefore, have a high apparent intensity.

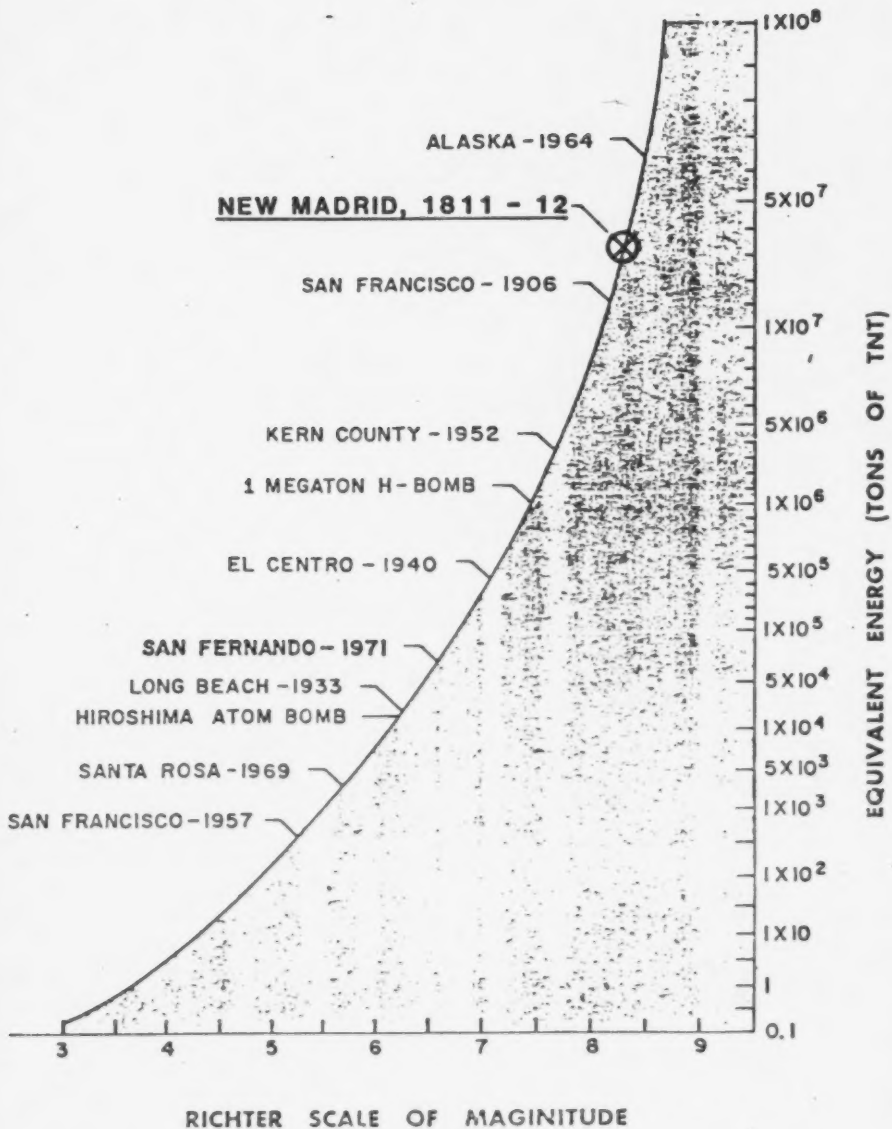
By using the relationship between the amount of TNT and associated energy produced by it, the Richter scale magnitude versus the energy equivalent in tons of TNT is plotted in Figure _____ with several earthquakes indicated on it.

Seismic Waves

Ground motion is excited by the propagation of waves which emanate from the hypocenter (source) of an earthquake. There are four basic seismic waves: two preliminary "body" waves which travel through the earth and two which travel only at the surface. The total wave propagation pattern is shown schematically in Figure _____. Combinations, reflections, and diffractions produce countless number of waves of other types. In addition, a large earthquake generates inelastic waves.

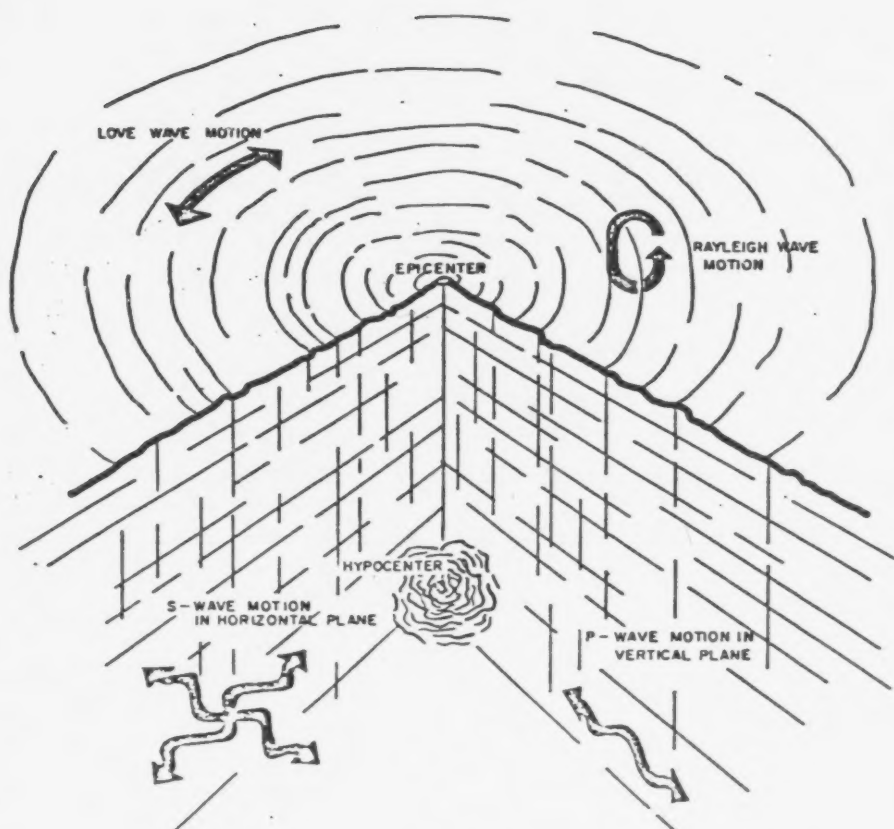
The two body waves are the primary (P) wave and the secondary (S) wave. The P wave travels about twice as fast as the S wave, and is the first instrumental indication that an earthquake has occurred.

The P wave is longitudinal, like a sound wave, and propagates through both liquids and solids. It travels about 4 miles per second or nearly 15,000 miles per hour. As the compressional P wave passes through the earth's crust, an object embedded in the ground or on the surface is subjected to a series of sharp pushes and pulls parallel to the wave path-motion similar to that which the passengers feel when a long train gets under way.



Comparison of Richter Scale Magnitude versus Equivalent Energy of TNT.

Figure



Elastic earthquake generated waves.

Figure

The S wave is transverse, like a light or radio wave, and travels barely more than half as fast as the P wave. As this wave travels, it displaces objects at right angles to the direction of wave travel. There is hardly any vertical motion association with the S wave, as the vertical component is damped by the opposing force of gravity, however, side-to-side shaking in the horizontal plane can be extremely destructive.

Surface waves, Love and Rayleigh waves, are of much greater length and period, such as 30 seconds or more versus less than one second for P waves. The Love wave produces lateral shear in the horizontal plane, and the Rayleigh wave induces a retrograde, elliptical motion, similar to wind-driven ocean waves. The speed of the Love wave is about 2.5 miles per second and the Rayleigh wave is about 10 percent slower [3.1].

Because of the waves generated by an earthquake travel at different speeds, the seismic waves arrive at a given point at different times. A recording station located at a great distance could record a single event for days as reflected, combined, and resonated waves propagate through the earth's mantle and core.

The first indication of an earthquake is signaled by the arrival of the compressional (P) waves. This will be followed by the shear (S) waves and then the "ground roll" caused by the surface waves. When compared with the body waves (P and S), the surface waves usually have the stronger vibrations and probably cause most earthquake damage.

The vibrations induced by earthquakes are detected, recorded, and measured by seismographs. In the region of strong ground motions near a high-energy source, "strongmotion" seismographs are used. These seismographs are usually installed in tall and large buildings, in some

dams and bridges, and at nuclear reactor sites. They are triggered by the earthquake-generated vibration above a given threshold amplitude, so that the onset of the earthquake motion is usually lost. However, the lost portion of the record has little value to earthquake engineering which is primarily concerned with the earthquake-resistance design of structures.

Section II Project Methodology

INTRODUCTION AND GENERAL APPROACH

As discussed earlier this phase of the project relies on three main project components. The first is the extensive inventory of structural and other data collected in the project cities by teams of FEMA personnel and volunteers from the cities. The next are estimations of the severity of ground shaking or earthquake effects upon the six cities as prepared by the USGS. The final element is the estimation of damage and casualties for the six project cities using the two preceding elements of information.

This discussion will describe how these first two items were interfaced, adjusted and utilized to produce the third. Since these first two elements were not a product of this project, but were supplied to us by or through FEMA, their individual production methodologies will only be referenced as needed to describe their effects on the methods used to produce damage and casualty estimations.

Collection of Base Data Inventories

The purpose of this data base as collected by FEMA was to provide a sufficiently detailed inventory of relevant construction and structural factors and associated population and occupancy data to allow for estimations of damage and casualties should these structures and populations be exposed to ground shaking as experienced in a major earthquake. During 1982 FEMA completed the very difficult and complex task of collecting, for the six project cities, a massive amount of detailed and descriptive information pertaining to structures, population, utilities and essential services. FEMA formulated the

methodology for this data collection, with assistance from the U.S.G.S. Earthquake Prediction Center in Golden, Colorado, and participated in its collection along with assistance from

the states and six project cities. Although variation from city to city was unavoidable in data collection, a generally consistent data base was assembled as a result of these efforts. Project team members undertook to improve upon this first collection, doing so with field trips to each project city, and other methods. During these field trips, a structural engineer and engineering technician reviewed the previously collected data, and then performed various field checks to verify the data and insure consistency. Field teams personally visited crucial structures such as hospitals and power stations and other critical facilities, and collected such additional needed information as time and circumstances allowed.

The following is a generalized outline of the data base which was assembled for each city and used for analysis in this project. Data was not always able to be collected for every category for each city; however, usable information was assembled for all or most categories for all cities.

I. Medical Resources

A. Major Hospitals

1. Structural
2. Emergency Power
3. Building Occupants, Staff and Patients

B. Health Manpower

1. Health Care Workers for Entire City

C. Nursing Homes

1. Structural
 2. Emergency Power
 3. Occupants, Staff and Patients
- D. Blood Banks
1. Structural
 2. Emergency Power
- E. Ambulance Services
1. Structural
 2. Numbers and Locations of Vehicles

II. "Critical" Structures

- A. Public Structures; Municipal/Administrative Buildings,
Fire and Police Stations, Governmental/Emergency
Communication Centers, Etc.
1. Structural
 2. Building Occupancy
- B. Communications; Radio, Television, Telephone Systems,
Towers and Buildings
1. Structural
 2. Building Occupancy
- C. Transportation Systems; Rail, Highway, Airport, River/
Ports
1. Structural, Bridge Information
 2. Other System Features
- D. Public Utilities; Electrical, Natural Gas, Water and
Sewage
1. Structural
 - a. "Key" Elements; Substations, Treatment Plants,

Storage Tanks and Towers, Etc.

- b. Transmission Line and Feeder Line Locations
- c. Other Relevant System Factors

E. Schools

- 1. Structural
- 2. Building Occupancy; Staff and Students

F. Dams and Levees

- 1. Structural
- 2. Location
- 3. Other Relevant Factors

III. Commercial and Other Non-Residential Structures

- A. Structural Information
- B. Location

IV. Residential (Single and Multi-Family Housing)

- A. Structural Information
- B. Location

V. Population

- A. Census Data
- B. Census Tract Locations
- C. Other Information, i.e., Transportation Plans, Origin and Destination Studies, Etc.

Three basic data inventory forms were used to record and compile crucial structural, construction, and occupational information; these are shown in Figures ____, ____, _____. They are, respectively, the Critical Facilities Field Inspection Building Data Sheet ("critical facilities" sheet), the Commercial and Other Non-Residential Structures

CRITICAL FACILITIES
FIELD INSPECTION BUILDING DATA SHEET

1. NAME OF BUILDING _____ CENSUS TRACT _____
2. BLDG. ADDRESS _____ CITY _____ COUNTY _____
3. NO. OF OCCUPANTS _____ DAY _____ NIGHT _____
4. YEAR BUILT _____ 5. BLDG. SIZE (SQUARE FEET) _____
6. NO. OF STORIES/FLOOR _____ 7. BASEMENT? YES _____ NO _____
8. PRIMARY STRUCTURAL SYSTEM
 - _____ A. STEEL FRAME
 - _____ B. STEEL FRAME (REINFORCED CONCRETE SHEAR WALL AROUND CENTRAL CORE)
 - _____ C. WALL BEARING
 - _____ D. PRECAST COLUMN AND BEAM
 - _____ E. REINFORCED CONCRETE FRAME
 - _____ F. REINFORCED CONCRETE FRAME (REINFORCED CONCRETE SHEAR WALL AROUND CENTRAL CORE)
 - _____ G. FLAT PLATE CONCRETE SLAB
 - _____ H. WOOD FRAME
 - _____ I. PLANK AND BEAM FRAME
 - _____ J. PRE-ENGINEERED METAL BUILDING
 - _____ K. OTHER STRUCTURAL TYPES DESCRIBE _____
9. FOUNDATION TYPE
 - _____ A. SPREAD
 - _____ B. STRIP
 - _____ C. PILES
 - _____ D. CAISSONS
 - _____ E. SLAB ON GROUND
 - _____ F. OTHER
10. WALL TYPE _____
11. FLOOR/ROOF TYPE _____
12. SPECIAL FEATURES _____
13. SPECIAL SOIL CONDITIONS _____

CENSUS TRACT _____

	COMMERCIAL	NON-EDUCATIONAL	PUBLIC	UTILITIES	INDUSTRIAL	EDUCATIONAL
<u>NO. OF BLDGS.</u>						
STEEL FRAME						
WALL-BEARING						
CONCRETE FRAME						
FLAT PLATE						
WOOD FRAME						
PLANK AND BEAM						
PRE-ENGINEERED METAL						
1 STORY/FLOOR						
2-5 STORIES/FLOORS						
6-10 STORIES/FLOORS						
OVER 10 STORIES/FLOORS						
AGE PRIOR 1900						
1900-1929						
1930-1949						
1950-1969						
1970-PRESENT						

SINGLE AND MULTI-FAMILY HOUSING DATA SHEET

TRACK (DISTRICT) _____

TY _____ COUNTY _____

SINGLE FAMILY RESIDENCES

- 1) PREDOMINATE FOUNDATION TYPES
 A. _____ SLAB ON GROUND
 B. _____ POURED CONCRETE OR MASONRY BLOCK FOUNDATION WALLS
 C. _____ STONE FOUNDATION WALLS
 D. _____ OTHER
- 2) PREDOMINATE EXTERIOR WALL, VENEER OR FINISH
 A. _____ BRICK/MASONRY
 B. _____ STONE
 C. _____ WOOD-SIDING OR SHINGLES
 D. _____ STUCCO
 E. _____ OTHER
- 3) CHIMNEYS, PARAPETS, ORNAMENTATION OR OTHER FALLING HAZARDS _____
- 4) AGE _____ 5) HEIGHT _____
- 5) NO. OF OCCUPANTS DAY _____ NIGHT _____

MULTI-FAMILY RESIDENCES

- 1) PREDOMINANT STRUCTURAL TYPE
 A. _____ STEEL FRAME
 B. _____ WALL BEARING
 C. _____ CONCRETE FRAME
 D. _____ FLAT PLATE
 E. _____ WOOD FRAME
 F. _____ PLANK AND BEAM
- 2) NO. OF OCCUPANTS DAY _____ NIGHT _____
- 3) AGE _____ 4) HEIGHT _____
- 5) STORIES/FLOORS _____

Sheet ("non-residential" structures sheet) in the Single and Multi-Family Housing Data Sheet ("residential" structures data sheet). By exhaustive implementation of data collection methods, the FEMA methodology provided for the inventorying of essentially all structures within the project cities which would be occupied either during the work day or during traditional non-working "at home", (i.e., evenings, weekends and holidays), or which were structures associated with vital and essential urban services and facilities.

The prime and most basic unit of location within a project city was the census tract. Census tracts were coordinated with zones of predicted ground shaking intensities so that structures in each tract could be evaluated for damage. Inventory data was used for those tracts within the corporate or city limits of each project city only.

Project team personnel, upon receipt of this inventory data from FEMA performed an extensive review and initiated two immediate inventory-related activities. The first was the development of formating and the entering of all inventory data into computer memory for subsequent analyses. This task resulted in the entry of over 3,700 data "sets", each set containing from one to four lines and from ten to thirty individual pieces of information. These sets included information for over 2,400 individual critical facility structures. The data was distributed into over 230 census tracts comprising the six project cities.

The second activity was to formulate and complete several measures intended to check the overall accuracy and thoroughness of the data inventory, and to correct, improve, and enhance the data inventory as needed, to the extent possible. As mentioned briefly earlier, field trips to each project city were made to check as many kinds of inventory elements as possible. In addition to checking data already acquired, field crews visited locations such as hospitals, power stations, other utility elements, statistical centers, and other localities to gather additional needed information. At some locations, questionnaires relevant to the project were completed by individuals contacted by the project field teams. Both the field teams and the project team in the home office performed extensive telephone surveys and interviews to gather information from various agencies and individuals. Team personnel contacted, by telephone, mail or in person, the following persons/facilities in the six project cities: hospital managers administrators and emergency supervisors, municipal and regional emergency managers and planners, blood banks, nursing homes, ambulance stations, utilities managers (water, electric, gas, sewer), communications managers (radio, television, telephone) and others.

Estimates of Ground Shaking and Soils Behavior

The task of estimating the effects of this project's hypothetical or "planning" earthquake fell to the United States Geologic Survey, USGS. The project earthquake was selected by FEMA, with the guidance of other seismic experts, to be ^amaximum - type or "great" earthquake, which was postulated to occur anywhere along the known active portions of the

New Madrid Fault system. This earthquake was generally assumed to be equivalent in strength to the largest of the three 1811/1812 shocks, of Richter magnitude approximately 8.6. Since resources were not available to study the effects of multiple earthquake scenarios, a maximum - level event was chosen to give planners a top or maximum limiting view of the scale of disaster to be expected. Emergency managers could then scale down estimates of required response actions and materials for less severe but still damaging quakes which have a greater likelihood of occurrence than the maximum - level project quake. The sole use of a lesser magnitude, "medium" intensity earthquake for planning purposes would have left the high range of the disaster spectrum undefined, and thus emergency managers would be left without needed guidance for resource allocations to respond to quakes in this upper range of magnitude, quakes which definitely have a real probability of occurrence within meaningful time spans.

USGS, as previously mentioned, has prepared estimates of the seismic behavior of the Central United States region and for the six project cities. These results are contained in CUSEPP Report 82-3 (USGS open file report 83-179). Information in that report of direct use to this project is the depiction of the effect on the Central United States which would be produced by the project earthquake in terms of estimated ground shaking intensities, given in modified Mercalli intensities (MMI). These macro-scale estimates, shown in Figure , show expected levels of ground shaking by using isoseismals (lines of equal ground shaking or MMI intensity) to define the earthquake's effects as they radiate out from the fault zone.

From USGS Rep.

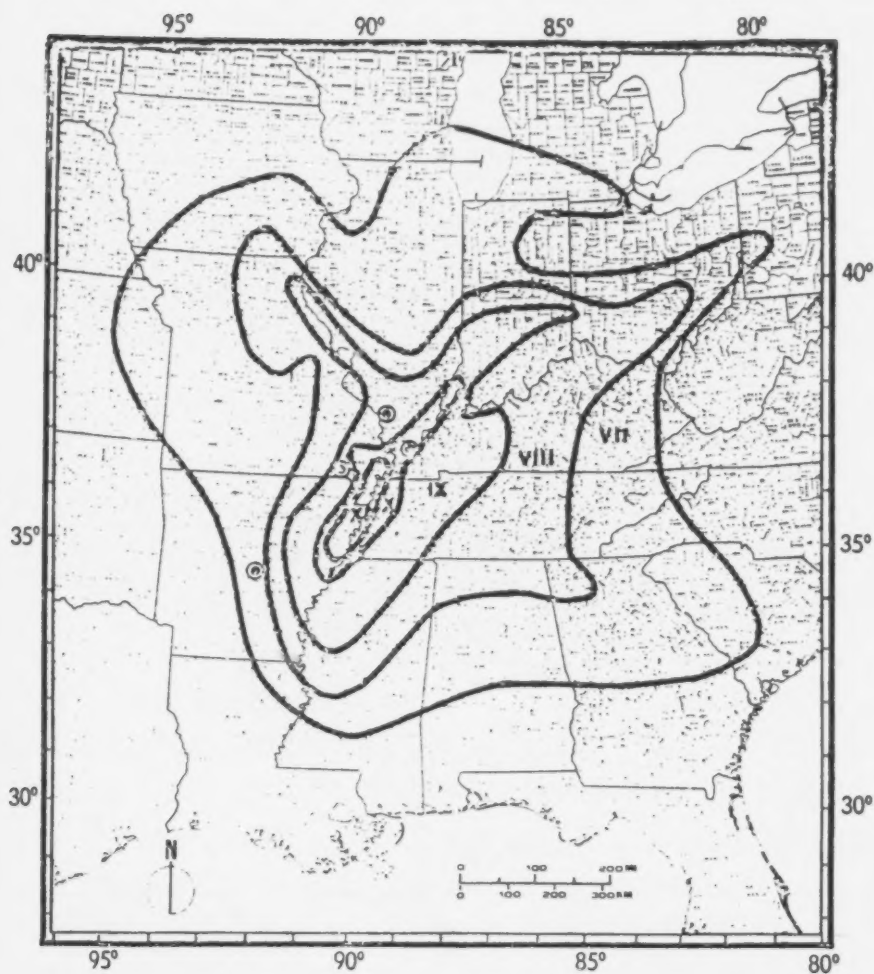


Figure 9. Hypothetical regional intensity map for an 1811-size earthquake having an epicenter anywhere along the New Madrid seismic zone (the zone of intense microseismicity in figure 8). Dots show the locations of the six cities in this study. The contours on this map are used to assign the county intensities shown in figure 16.

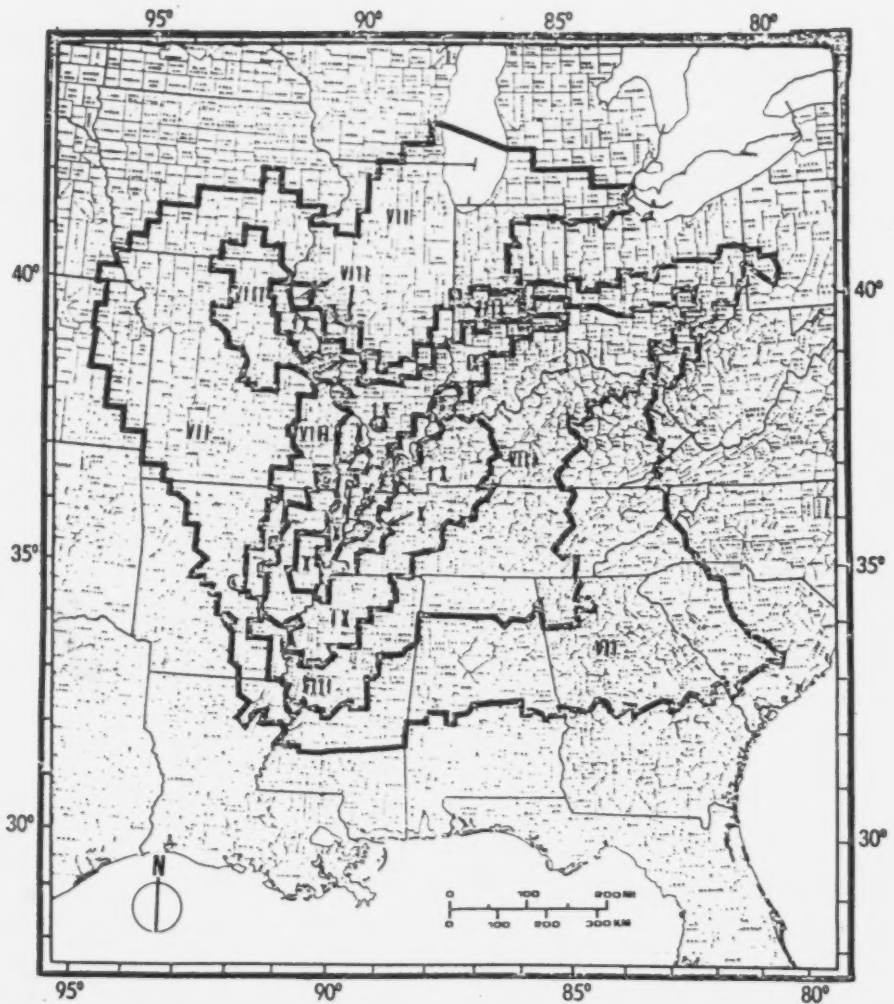


Figure 16. Hypothetical regional intensity map by county. Assumes an 1811-size earthquake having an epicenter anywhere along the New Madrid seismic zone. Dots show the locations of the six cities in this study.

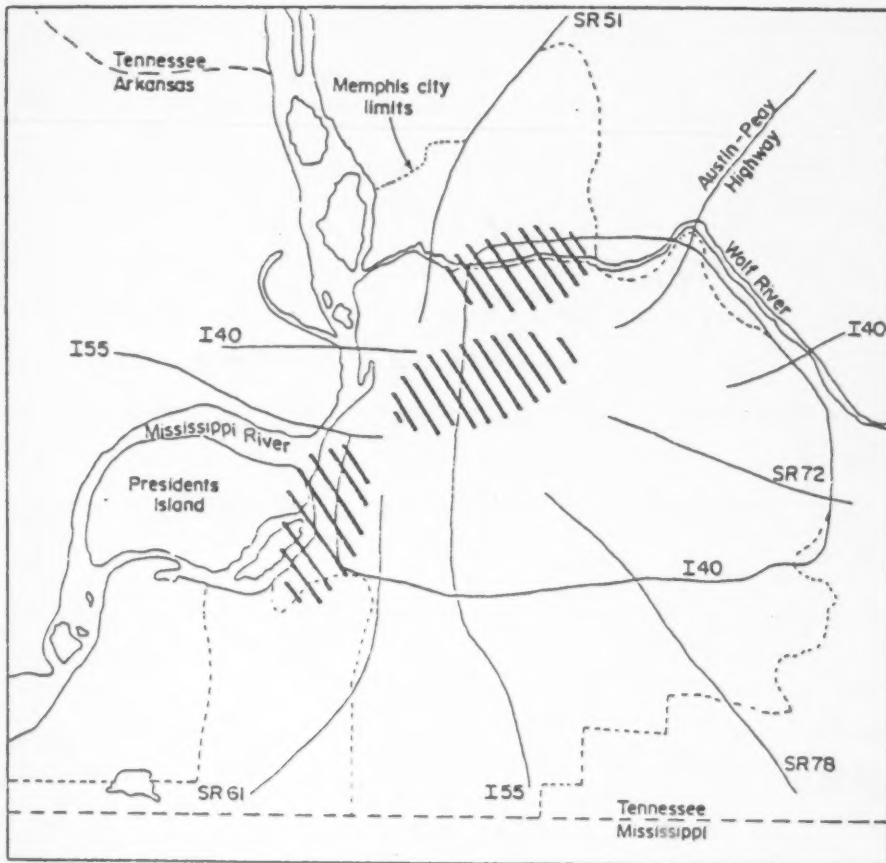
The same kind of estimates were performed on a micro-scale basis for the six project cities. All available sources of geologic and seismic information were used by USGS to predict the MMI's which would be experienced in these cities. Two general kinds of seismic factors, relevant to the behavior of structures, were addressed. The first was the generalized ground shaking expected to prevail over the city's zone. The second was adverse soils behavior, caused by the earthquakes ground shaking, which might cause a structure to be exposed to locally damaging effects more severe than those indicated by the prevailing levels of ground shaking. The factors of greatest interest and concern are soils liquefaction, with resulting loss of bearing capacity and differential compaction and settling of soils. Liquefaction occurs, under suitable conditions of ground shaking, when soil particles, in sub-surface regions saturated with ground water, temporarily "float" or experience a "quick" condition (like quicksand). Soils experiencing such a phenomenon ^{are} said to liquefy; when this occurs, a wide spectrum of frequently spectacular and bizarre events may result. In the project study area, land and mud slides would be one result, but the behavior of greatest interest is the damaging effect which liquefaction causes when it occurs beneath the foundation of buildings and other structures. When this happens, the soils beneath foundation temporarily lose their ability to support the structure (loss of bearing capacity), with catastrophic damage often resulting. Differential soils movement, both horizontal and in particular vertical, can also occur during ground shaking under conditions which may or may not differ from those present in liquefaction. For example a poorly compacted man made earth fill

which is supporting structural foundation, may subside or settle, uniformly or non-uniformly with resulting damage to the structure. Due to the prevailing soil conditions in the study area, ie, wide spread, deep unconsolidated and mostly saturated alluvial deposits (sands, gravel, silts and clays deposited by water - mostly by the meandering of the Mississippi River) with very little "bedrock", this region is felt to have a very high potential for local liquefaction ~~and~~ differential settlement, resulting from moderate, as well as severe, earthquakes.

Such adverse soils behavior may occur virtually anywhere in the study area. Without specific knowledge of sub-surface conditions, nothing more than a categorical warning of its risk can be made. Two exceptions ^{to} ~~of~~ this generality have been used by USGS in making more specific soils behavior predictions for the project cities. The first assumes that a higher potential for adverse soil behavior, when exposed to earthquake ground shaking, will exist along the path or flood plane of existing rivers and streams, where soils are generally known to have high saturation, poor characteristic, and frequently, steep and unstable banks. The second factor which allows for better defined soils behavior predictions is the existence for the city of Memphis, of a recent report which has compiled and examined existing soils boring well "logs" to produce a study of sub-surface conditions - a "microzonation". This report, The Microzonation of the Memphis, Tennessee, by Sharma and Kovacs of Purdue University (USGS open file report no. 80-914, another very good reference relating to this project) and shows, among other topics, areas which may be susceptible

to liquefaction within the city of Memphis, (Figure). This information was used by USGS to supplement its own analysis for the city of Memphis.

Although no such similar published reports exist for the other project cities, USGS compiled available and appropriate information to produce their ground shaking and soils behavior predictions. Areas thought to be subject to adverse soils behavior were designated with higher predicted MMI values. The isoseismal maps prepared by USGS for this study are shown in Figures____thru____. As discussed later, census tracts were overlaid upon these areas, within the city limits of the project cities, and a level of ground shaking was assigned for each census tract.



Shaded areas indicate zones where soils may be susceptible to liquefaction for earthquakes with Modified Mercalli Intensity greater than VII.
(see discussion in text)

FIG. 7-11, Liquefaction Potential microzonation map
for Memphis, TN

II.D. Damage Assessments

1. General

The estimation of damage to structures and systems within the project cities was performed utilizing a variety of approaches, dictated by prevailing circumstances. Major factors in determining how a particular analysis was performed were the type and level of desired results, and the quantity, quality and availability of information required for the selected analyses.

Damage assessments serve two basic purposes. The first is to support casualty estimation. The methodology for this work, described later in this section, uses a determined damage state for a structure or structural category to provide a basis for estimating the exposure of individuals to risk of death or injury. A second use of damage assessments was to estimate the actual availability of a structure or system, such as highway and rail bridges, and of "critical facilities" (i.e., hospitals, electric substations, etc.).

The assessments performed for this project relied heavily upon the fragility curve method of estimating damage to structures, which is discussed later in this section. This methodology is well suited to the goals and requirements of the project and was invoked for virtually all estimates performed for the numerous structural categories examined.

Damage assessments were performed using fragility curve methods and guidance whenever possible; this was the normal analysis method used for the majority of assessments. In addition, some analysis items (such as utility distribution networks) required subjective assessments for their investigations. All damage assessments incorporated the judgment of experts for the specific structural and system types, to enhance and augment the basic fragility curve applications.

Fragility Curve Methodology

Background

Although earthquake-induced damage and failure of a structure may result from a variety of mechanisms: ^{e.g.,} foundation failure due to liquefaction, foundation displacement caused by fault break or landslide, etc., damage and failure is principally due to the shaking of the ground. As a result of ground shaking, vibration is developed in a structure. For engineering purposes, the level of ground shaking and the vibration in a structure is most often expressed in terms of acceleration. Due to the inherent dynamic characteristics of structures, the level of the vibration in most structures is significantly greater than the level of shaking in the ground. For small levels of vibration in a structure, damage is minor or does not occur at all. At larger levels of vibration, damage becomes more significant and failure more likely.

The actual damage that will be inflicted on a structure by a particular level of ground shaking is uncertain because of (1) design and construction irregularities, (2) variability in material properties, (3) uncertainty in structural response to earthquake-induced shaking, and (4) uncertainty in the level of ground shaking that will cause a structure to fail. However, it is possible to define a range of ground shaking over which failure can occur. Within this range, the assessment of the likelihood of failure increases from a probability of zero (i.e., no chance of failure) to a probability of one (e.g., certain failure).

The relationship which describes the probability of failure at various levels of ground shaking is known as a "fragility" curve. For the

purpose of emergency management planning, fragility curves can be used, in conjunction with estimates of the severity of ground motion intensity, to predict the probability that a structure will fail and the degree of damage that it is liable to sustain. The level of ground shaking is most commonly expressed in ~~terms~~ of the peak ground acceleration (PGA); however, Modified Mercalli Intensity (MMI) can be used as well.

Peak ground acceleration is the maximum value of ground shaking recorded by an instrument known as an accelerograph. Peak ground acceleration is preferred by engineers to describe seismic loads and is the most commonly used parameter to characterize ground shaking. Modified Mercalli Intensity is a subjective measure of the level of ground shaking that ranges numerically from I to XII. Each value on the MMI scale corresponds to observations of damage and sensations experienced as a result of the earthquake. For earthquakes with recordings of PGA and MMI, a correlation between these parameters has been observed and equations relating them are available. Table II.D.1 provides a description of the Modified Mercalli Intensity scale and a range of PGA values for each intensity. For this project, maps of the ground motion intensity corresponding to a New Madrid earthquake were provided by the USGS as previously described in Section II.C.

Fragility Curve Description

A fragility curve can be used to represent failure of a specific structure, a structural system, or a generic type of structure. For this project, fragility curves were developed for the 16 structures types (or structural systems) listed in Table II.D.2. Further, the fragility curves were prepared in two basic formats: one format which

describes the probability of failure for "all" structures of a given type (e.g., all bearing wall buildings), and a second format which delineates the probability of failure for "good" structures, "average" structures or "bad" structures of a given type (e.g., good bearing wall buildings, average bearing wall buildings, or bad bearing wall buildings).

Thus, if a specific structure or group of structures could be distinguished as either good (i.e., significantly better than average), average, or bad (i.e., significantly worse than average) in terms of anticipated seismic performance, then the corresponding "good", "average", or "bad" fragility curves were used to determine the likelihood of failure. On the other hand, if a structure of a given type could not be distinguished as good, average or bad in terms of anticipated seismic performance, then the "all"-structure fragility curve was used to determine the likelihood of failure.

Traditionally, fragility curves assume a structure to be in one of two possible states: completely failed or not failed. For some structure types, such as electrical switchyard equipment, two-state modeling accurately represents observed failure patterns. However, for most structures, and especially buildings, damage is observed to occur in varying degrees from no damage to collapse.

To described multiple damage states for buildings (and other structure types), fragility curves were developed which quantify the probability of reaching one of five damage states: nonstructural, slight, moderate, severe and collapse. These five damage states are described in Table II.D.3. For structures such as bridges, tanks, etc., only the moderate, severe and collapse damage states were used since

TABLE
MODIFIED MERCALLI INTENSITY SCALE

<u>Intensity</u>	<u>Description</u>	<u>PGA Interval¹</u> (g units)
I.	Not felt except by a few under especially favorable conditions.	0.03
II.	Felt only by persons at rest in places such as upper floors of buildings. Delicately suspended objects swing.	0.03
III.	Felt by many persons in places such as upper floors of buildings but of a degree that most persons do not recognize it as an earthquake. Standing automobiles may rock slightly as if from vibration caused by a passing truck. Duration may be measured.	0.03
IV.	In daytime, felt by many indoors but by only a few outdoors. Dishes, windows, doors disturbed, and walls creak. Sensation like a heavy truck striking a building. Standing automobiles rocked considerably.	0.03
V.	Felt by all, many awakened. Some dishes and window glasses broken, wall plaster may crack. Unstable objects overturned. Disturbance of telephone poles, trees and other tall objects sometimes noticed. Pendulum clocks stopped.	0.03-0.08
VI.	People are frightened and run outdoors. Heavy furniture may be moved; some instances of fallen plaster and toppling of chimneys. Slight damage.	0.09-0.15
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in ordinary structures, and considerable in poorly built or badly designed structures. Chimneys broken. Felt in moving automobiles.	0.16-0.25
VIII.	Some damage even in buildings of good design and construction. Considerable damage in ordinary buildings, with some collapsing. Great damage in poorly constructed buildings. Panel walls thrown out of frame structures. Falling of houses and factory chimneys, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Hinders driving of automobiles.	0.26-0.45

<u>Intensity</u>	<u>Description</u>	<u>PGA Interval¹</u> (g units)
IX.	Damage considerable in buildings of good design and construction. Structures thrown out of alignment with foundations. Ground cracked conspicuously. Underground pipes damaged.	0.46-0.60
X.	Wooden houses of good design and construction collapse. Most masonry and frame structures destroyed together with foundations. Ground cracked causing damage. Rails bent. Slopes and embankments slide. Water surface rises.	0.61-0.80
XI.	Almost all masonry structures collapse. Bridges destroyed. Fissures over entire surface of ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent prominently.	0.81-0.90
XII.	Damage total. Waves seen transmitted at ground surface. Topography changed. Objects thrown into air.	0.91
1.	PGA Interval (g units) from: McCann, M.W., Sauter, F., and Shah, H.C., 1980	

TABLE II.D.2
STRUCTURE TYPES

1-5/Story shear wall buildings
6/Story shear wall buildings
Bearing wall buildings
Wood frame buildings
Pre-engineered metal buildings
Tilt-up buildings
Pre-cast buildings
Electrical switchyard equipment
Emergency power units
Water/sewage plants
Power plants
Earth dams
Highway bridges
Major bridges
Cylindrical storage tanks
Elevated tanks

TABLE II.D.3
DAMAGE CATEGORIES¹

Response Level	Damage Category	Extent of Damage in General	Suggested Post-Earthquake Actions
	0 No Damage	No Damage	No Action Required
Elastic I	Slight Non-structural Damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Building need not be vacated. Only architectural repairs needed.
Inelastic II (yielding of some elements)	Slight Structural Damage	Small cracks, in walls, falling of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
Inelastic III (general yielding)	Moderate Structural Damage	Large and deep cracks in walls; widespread crack of walls, columns, piers and tilting or falling of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated, to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architectural treatment may be carried out.
Inelastic IV (ultimate of some elements)	Severe Structural Damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate parts of buildings. Approximately 50% of the main structural elements fail. The building takes a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
Inelastic V (ultimate all main elements)	Collapse	A large part of whole of the building collapse.	Clearing the site and reconstruction.

1. from: Basic Concepts of Building Codes, Vol. I, International Association of Earthquake Engineering, Tokyo, Japan, 1980

nonstructural and slight structural damage is not of interest for emergency planning purposes. As mentioned previously, for structures such as electrical switchyard equipment, which respond with either no damage or complete failure, a single damage state (i.e., collapse) was used.

The function of each fragility curve is the quantification of the likelihood of reaching or exceeding a particular damage state, given the severity of the ground motion. For example, the likelihood of building collapse (and, consequently, the likelihood of related casualties, etc.) is dependent on the level of ground shaking. At a very low level of ground shaking, one can be almost certain that the building would not collapse. Conversely, at a very high level of ground shaking, one can be reasonably sure that the building would collapse. Between these extremes it is uncertain whether the building would or would not collapse. The absolute likelihood of collapse at any level of shaking depends on details of design, construction, and earth movement that are not known for a hypothetical earthquake. The function of the fragility curve is to assign, in this case, different probabilities of collapse, having taken into account each source of uncertainty.

Fragility Curve Development

The fragility curves are based on a combination of calculations, engineering judgement, and damage data from past earthquakes. A detailed description of the procedures, assumptions, sources of damage data, etc., which were used to determine each fragility curve, is given separately in Appendix A. A brief summary of the overall process is described below.

In essence, two separate approaches, one based on calculations and one based on data, were used to determine the fragility parameters for each curve (i.e., the medium peak acceleration and the associated variability). The first approach relied upon calculations (and engineering judgements) to develop fragility parameters for specific geometrics, materials, etc. which were deemed to best represent the characteristics of structures found in the Mississippi Valley region. The second approach relied upon the analysis of damage data from past earthquakes. The two approaches were conducted in parallel and composite fragility parameters were developed by subjective weighting and combination of the individual results. In this manner, the fragility curves represent structures specific to the Mississippi Valley, but calibrated by the general patterns of observed earthquake damage.

Fragility Curve Illustration

Figures II.D.1 and II.D.2 illustrate the fragility curves developed for this project. In this illustration Figure II.D.1 is the "all"-structure fragility curves for wood frame buildings while Figure II.D.2 is the "good"-, "average"- and "bad"-structure fragility curves also for wood frame buildings. For each damage state in Figure II.D.2, a shaded region between upper- and lower-bounds is used to represent the range of possible fragility values for "good" to "bad" wood frame buildings.

The meaning of the fragility curves may be illustrated by examining values extracted from the slight structural damage fragility curve shown in Figure II.D.1.

For an earthquake intensity of MMI VI, it is almost certain that

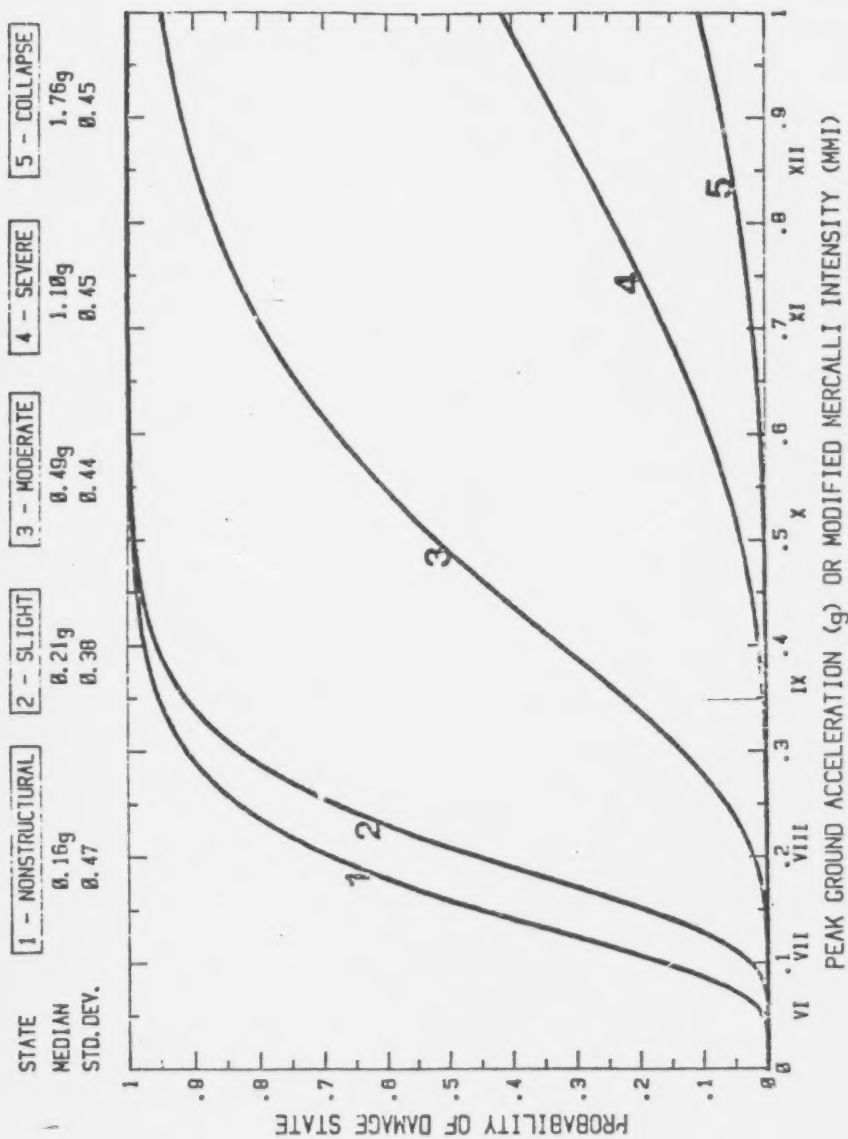


FIGURE II.D.1 STRUCTURE TYPE : ALL WOOD FRAME BUILDINGS

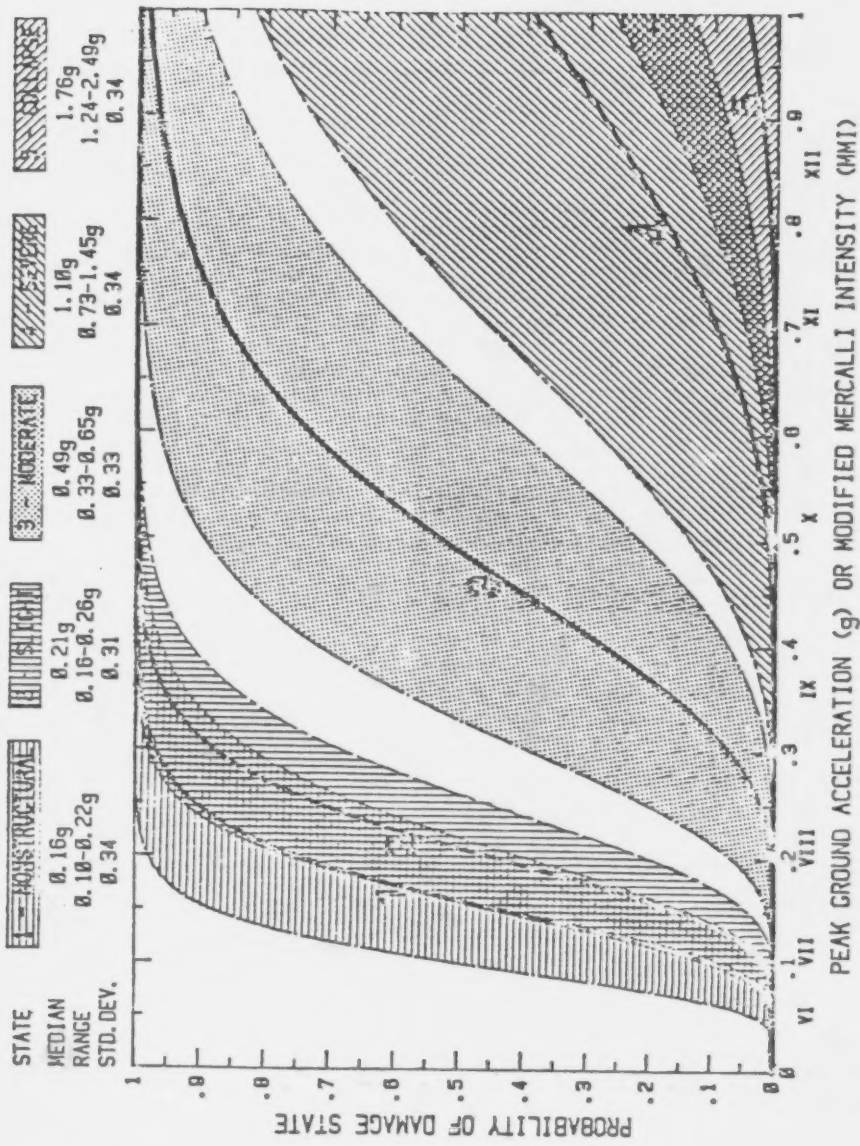


FIGURE 1.02 STRUCTURE TYPE : MEDIAN, UPPER AND LOWER BOUND WOOD FRAME BUILDINGS

only nonstructural damage would occur to a typical wood frame building. Therefore, the probability of slight structural or greater damage at MMI VI is 0.0. For an earthquake intensity of MMI XII, it is almost certain that structural damage to a wood frame building would be at least slight. Therefore, the probability of slight damage at MMI XII is approximately 1.0. At intermediate earthquake intensities, the probability of at least slight damage is greater than 0.0 and less than 1.0. For example at MMI VIII, the probability of at least slight damage is 0.45. This means that if a wood frame building is subjected to an MMI VIII shock 100 times, it would be reasonable to expect at least slight structural damage on 45 of those occasions. From another viewpoint, if one had 100 wood frame buildings of unknown quality that were all subjected to an MMI VIII shock, then one might reasonably expect that 45 of the buildings would suffer at least slight structural damage.

Further, at any given intensity we find a higher likelihood of moderate structural damage than of severe structural damage, a higher likelihood of slight than moderate, etc. Thus, for a wood frame building of unknown quality (i.e., Figure II.D.1) and earthquake intensity MMI IX, there is:

- a 0.95 probability of at least nonstructural damage,
- a 0.91 probability of at least slight structural damage,
- a 0.23 probability of at least moderate structural damage,
- a 0.01 probability of at least severe structural damage,
- a 0.00 probability of collapse.

Hence, for a given earthquake intensity, the fragility curves provide a

measure of the likelihood of reaching or exceeding each damage category.

The meaning of the information contained in the "good"-, "average"-, and "bad"-structure fragility curves is the same as the "all"-structure fragility curves, except a range of values is given for each damage state. For example, a wood frame building of known quality (i.e., Figure II.D.2) and subjected to an earthquake intensity of MMI IX, has:

- a 0.60 probability of at least moderate damage, if it's a "bad" wood frame building,
- a 0.16 probability of at least moderate damage, if it's an "average" wood frame building,
- a 0.03 probability of at least moderate damage, if it's a "good" wood frame building.

Each damage category has a range of values which represent the variability of the structure's quality.

Comparison of Fragility Curves Probabilities
and Coalinga Damage Data

On May 2, 1983, at 4:42 p.m. a moderate ($M_L = 6.5$) earthquake struck near Coalinga, California. The reported duration of strong shaking was about 10 to 15 seconds. Preliminary estimates of maximum intensity was MMI IX.

This event is of particular relevance to the Mississippi Valley earthquake impact study, since many of the older masonry and wood frame buildings of Coalinga are similar in design to buildings found in the Mississippi Valley. That is, these structures were not designed for seismic forces. As a result of the Coalinga event, most older

structures, which lacked adequate seismic design, were severely damaged or collapsed. In fact, damage to the older buildings in the center of the town was so severe that the entire area was eventually razed.

Immediately following the Coalinga earthquake the Earthquake Engineering Research Institute dispatched a reconnaissance team under the leadership of Prof. Hareesh Shah of Stanford University to survey the damage. The results of the team's preliminary survey of 139 buildings are given in Table II.D.4, which is taken directly from the preliminary report on damage to the Coalinga commercial district (Ref. II.D.3). The pertinent damage ratios given in Table II.D.4 for bearing wall (masonry) and wood frame structures were extracted from this table, expressed in a cumulative form and compared to the corresponding fragility curve probability. Table II.D.5 and Table II.D.6 show this comparison for bearing wall and wood frame buildings, respectively. The conclusions reached are discussed below.

In general, very good agreement is found between the fraction of bearing wall or wood frame buildings which were observed to have suffered a particular level of damage and the probability of reaching that state, as given by the appropriate fragility curve. For instance, identical values were found for the damage experienced by old or poorly constructed, unreinforced masonry buildings and the probabilities predicted by the "bad" bearing wall fragility curves at MMI IX. This close agreement between observed damage and predicted value is particularly significant, since this structure type (i.e., unreinforced masonry) is very common to the Mississippi Valley and figures dominantly in estimates of earthquake casualties.

TABLE
NUMBER AND EXTENT OF BUILDINGS DAMAGED BY THE COALINGA EARTHQUAKE¹

Damage Ratio	Old unreinforced masonry buildings	Newer brick masonry buildings	Concrete block buildings	Wood framed commercial buildings	Cast-in-place concrete (frames & walls)	Old wood frame residences on cripple walls
0-10%	0	5*	14*	24*	5	4
10-30%	3	7*	2*	3	1	12
30-60%	7	1**	0	1	0	1
60-100%	30	2**	0	1***	0	16(a)
Total Number of Buildings	40	15	16	29	6	33
						139

¹ Table II.D.4 taken from Reference II.D.3.

* Reinforced brick or block masonry.

** These were new but unreinforced masonry.

*** This building collapsed because an adjacent unreinforced masonry building wall fell on it.

(a) Either the residence fell off the foundation or the cripple wall failed, resulting in buckled walls and roof.

TABLE
COMPARISON OF COALINGA DAMAGE FRACTIONS AND FRAGILITY
CURVE PROBABILITIES FOR BEARING WALL BUILDINGS

Structure Description	Damage State	Observed Damage Coalinga ¹		Fragility Curve Probability ²	
		Damage Ratio Range	Fraction Damaged	MMI=IX	MMI=X
"Bad" Bearing Wall (40 old or poorly constr., unreinforced masonry buildings)	Collapse	60-100%	0.75	0.75	0.92
	Severe	30-100%	0.93	0.93	0.98
	Moderate	10-100%	1.00	1.00	1.00
	Slight	0-100%	1.00	1.00	1.00
"Good" Bearing Wall (31 newer brick - or reinforced masonry buildings)	Collapse	60-100%	0.06	0.02	0.06
	Severe	30-100%	0.10	0.05	0.19
	Moderate	10-100%	0.39	0.55	0.84
	Slight	0-100%	1.00	0.82	0.95
"All" Bearing Wall (total population of 71 buildings)	Collapse	60-100%	0.45	0.28	0.45
	Severe	30-100%	0.56	0.41	0.59
	Moderate	10-100%	0.73	0.85	0.95
	Slight	0-100%	1.00	0.96	0.99

¹ Data taken from Reference II.D.3.

² Probabilities are taken from Bearing Wall fragility curves.

TABLE
COMPARISON OF COALINGA DAMAGE FRACTIONS AND
FRAGILITY CURVE PROBABILITIES FOR WOOD FRAME BUILDINGS

Structure Description	Damage State	Observed Damage Coalinga ¹		Fragility Curve Probability ²	
		Damage Ratio Range	Fraction Damaged	MMI=IX	MMI=X
"Bad" Wood Frame (33 older residences on cripple walls)	Collapse	60-100%	0.00 ³	0.00	0.00
	Severe	30-100%	0.52 ³	0.02	0.13
	Moderate	10-100%	0.88	0.60	0.90
	Slight	0-100%	1.00	0.99	1.00
"Good" Wood Frame (28 newer, commercial buildings)	Collapse	60-100%	0.00 ⁴	0.00	0.00
	Severe	30-100%	0.04	0.00	0.00
	Moderate	10-100%	0.14	0.03	0.22
	Slight	0-100%	1.00	0.85	0.98
"All" Wood Frame (total population of 61 buildings)	Collapse	60-100%	0.00 ⁴	0.00	0.00
	Severe	30-100%	0.30 ³	0.01	0.04
	Moderate	10-100%	0.54	0.23	0.52
	Slight	0-100%	1.00	0.91	0.98

¹ Data taken from Reference II.D.3

² Probabilities are taken from Wood Frame Building fragility curves.

³ Although often a total loss (i.e., 60-100% damage), no wood frame structures collapsed. Therefore, these structures are considered to be severely damaged.

⁴ The building which collapsed due to collapse of a neighboring masonry building is excluded from the sample population.

Highway and Railway Damage Assessment Methodology

The objective of the assessment of probable damage to highways and railways was to determine the probability that different sections of major routes would be available for emergency response purposes, in addition to estimating the probable general level of overall damage to highway and railway structures. The analysis of route availability was based primarily on the probable damages to bridge structures in each section of highway and railway. In some areas of poor soils subject to liquifaction or ground failure, damages to the roadbeds themselves could also be incurred. However, in the absence of dependable data on ground conditions, the effects of liquifaction and ground failure on the roadbeds were not explicitly taken into account.

1. Data Processing Methods. Bridge inventory data were obtained from the FEMA resource data base for highway bridges and from data provided to FEMA by the railroad companies. Additional data in certain cases were requested and obtained directly from state highway departments and from the railroad companies to supplement the data provided by FEMA. Because of the large number of structures involved and because data were provided only for the major highway and railway routes in each city; the analysis was limited to those major routes. In some cases, when data were not available for a major route, bridge locations were determined as best as possible from the maps of the area which were available or could be obtained.

The data for each city were entered into data files using a microcomputer data base management package. The structures were then sorted by route and ordered by milepoint to facilitate the division of routes into sections. In general, section limits were set at intersections of the routes included in the study and at the city and county boundaries. Some sections were also

terminated at intersections with routes which were not included in the study. Once the data for the bridges were sorted and ordered, the damage assessment was performed manually, based on the characteristics of the structures and the application of the bridge fragility curves.

The assessments were carried out for the entire county in which each of the six cities is located. They were not limited to the urban areas of the cities themselves, since for transportation network analyses to be meaningful, they must generally be performed over a much wider area, especially for purposes of disaster relief planning. For the areas in the counties that were not covered by the earthquake intensity estimates provided by the USGS, the USGS intensities were used as a basis for estimating intensities in the other areas. In general, the prevailing intensity in each city was assumed, except in areas where the USGS increased the intensities to account for the effects of poor soil conditions. These estimates are considered to be adequate for purposes of assessing potential damages to the sections of the transportation network; they were required in order to obtain damage estimates for the county-wide networks.

2. Damage Assessment. In general, the vulnerability of bridges to damage from earthquakes is considered to be primarily a function of the number, height, and length of spans, and of the material and type of construction. For example, single span steel structures can generally be expected to suffer much less damage than multi-span pre-cast concrete structures. Seismic resistance is usually greater in continuous structures and in those consisting of spans linked across supporting piers than in structures in which the individual spans are not tied together.

In order to apply the fragility curve methodology, bridge classification schemes were developed based on the above-mentioned characteristics for

highway and railway bridges. The same fragility curves were applied to both types of bridges, except that railway bridges were considered to be somewhat more resistant than highway bridges for a given type of structure, since they carry less dead load. In general, to account for this difference, railway structures were classified one category higher (more resistant to damage), in comparison to comparable highway structures. Five bridge categories were defined: good, better-than-average, average, below average, and poor. Each bridge was classified according to these categories, and the probability of severe structural damage and/or collapse for each individual structure was estimated from the corresponding fragility curve, based on the MMI intensity expected at the bridge's location. The classification schemes are shown in Tables IID-1 and IID-2, and the damage probabilities associated with each bridge category at each intensity are shown in Table IID-3. The damage estimates for individual bridges are characterized by a very high level of uncertainty. They should not be taken as definitive statements of damage for individual bridges. They were developed primarily for use in combination with damage estimates for other bridges in each section, in order to gain a more reliable estimate of the probability that entire sections would be available for use after the postulated earthquake. The estimates are much more reliable in the aggregate than for individual structures.

Fragility curves were developed for typical smaller highway bridges and for typical major bridges over large rivers or waterways. In general, however, the approaches to these large bridges were considered to have a greater likelihood of failure than that of the main spans themselves, such that although a well-designed main span could survive the expected earthquake, the entire bridge could still be made unavailable for use because of damage to the more vulnerable approach spans. In each case where a major structure was involved, it was determined that the availability of the structure would depend not upon the probable damages to the main span itself, but upon damages

TABLE II-D-1

HIGHWAY BRIDGE DAMAGE CLASSIFICATION SCHEME

<u>Main Span Type¹</u>	<u>No. of Spans² (M.+App.)</u>	<u>Span Length (feet)^{3,4}</u>	<u>Bridge Classif.^{5,6}</u>
11x	-	≤ 30	Good
	-	> 30	Avr+
1xx	≤ 2	-	Avr
	> 2	-	Avr-
2xx	-	-	Avr
315	-	-	Bad
316	-	-	Bad
317	-	-	Bad
3xx	1	≤ 60	Good
	1	> 60	Avr+
	> 1	-	Avr
4xx	-	≤ 60	Good
	-	> 60	Avr+
5xx	≤ 2	-	Avr-
	> 2	-	Bad
6xx	-	-	Avr
7xx	≤ 2	-	Avr-
	> 2	-	Bad

Notes:

TABLE 11-D-1 (Cont.)

1.

SPAN TYPE CODE

<u>1st Digit</u>	<u>2nd and 3rd Digits</u>
1 Concrete	01 Slab
2 Concrete continuous	02 Stringer/Multi-beam or girder
3 Steel	03 Girder and Floorbeam System
4 Steel continuous	04 Tee Beam
5 Prestress concrete	05 Box Beam or Girders-Multiple
6 Prestress concrete continuous	06 Box Beam or Girders-Single or Spread
7 Timber	07 Frame
8 Masonry	08 Orthotropic
9 Aluminum, W.I. or C.I.	09 Truss-Deck
0 Other	10 Truss-Thru
	11 Arch-Deck
	12 Arch-Thru
	13 Suspension
	14 Stayed Girder
	15 Movable-Lift
	16 Movable-Bascule
	17 Movable-Swing
	18 Tunnel
	19 Culvert
	00 Other

2. The number of approach spans was not provided in the data. If an approach type was indicated, two spans were added to the number of main spans.
3. Average for entire structure.
4. If span length was more than 180; the classification was reduced by 1 category (i.e., avr. becomes avr-; avr- became bad, etc.).
5. Because of their usually greater height, approach spans to major bridges were generally reduced by 1 category. (Height data was not available).
6. If the data were insufficient, bridges were classified as average.

TABLE II-D-2
RAILWAY BRIDGE DAMAGE CLASSIFICATION SCHEME

Main Span Type ¹	No. of Spans (M.+App.)	Span Length (feet) ^{2,3}	Bridge Classif ^{4,5}
000	-	-	Avr
01X	-	-	Avr+
03X	-	≤ 50 total length	Good
	-	> 50 total length	Avr+
11X	-	≤ 30	Good
	-	> 30	Good
1XX	≤ 2	-	Avr+
	> 2	-	Avr
2XX	-	-	Avr+
370,070	-	-	Bad
3XX	1	≤ 60	Good
	1	> 60	Good
	1	-	Avr+
33X	-	-	Good
4XX	-	-	Good
5XX	≤ 2	-	Avr
	> 2	-	Avr-
6XX	-	-	Avr+
73X	-	≤ 50 total length	Good
		> 50 total length	Avr+
7XX	≤ 2		Avr
	> 2		Avr-
	unknown		Avr
8XX			Avr
9XX			Avr+

TABLE 11-D-2 (Cont.)

Notes:

1.

RAILWAY BRIDGE SUPERSTRUCTURE TYPE CODES

1st Digit

1 Concrete	6 Continuous prestressed concrete
2 Continuous concrete	7 Timber
3 Steel	8 Masonry (stone, brick)
4 Continuous steel	9 Reinforced concrete
5 Prestressed concrete	0 Don't know or other

2nd & 3rd Digits

10 Arch or box	40 Girder or beam
11 Arch bridge	41 Deck or deck plate girder
18 Cast iron pipe	42 Through or through plate girder
19 Culvert (arch or box)	43 Rail girder
	44 I-Beam
20 Truss	45 I-Beam encased in concrete
21 Deck truss	46 Timber stringers on masonry
22 Through truss	
23 Pony truss	50 Slab
	51 Slab on concrete
30 Trestle	52 Slab on masonry
31 Pile trestle	
32 Frame trestle	60 Suspension
33 Trestle with masonry footing	70 Draw span

2. If span length was more than 180, classification was reduced by 1 category.
3. Average for structure.
4. If height was more than 60, the classification was reduced by 1 category.
5. If the data were insufficient, bridges were classified as average.

TABLE II-D-3
BRIDGE DAMAGE PROBABILITIES

Bridge Classif	Probability of Severe Damage at MNI				Probability of Collapse at MNI			
	VI	VII	VIII	IX	X	VI	VII	IX
Good	0.00	0.00	0.00	0.02	0.14	0.00	0.00	0.01
Avg+	0.00	0.00	0.01	0.04	0.22	0.00	0.00	0.01
Avg	0.00	0.00	0.01	0.06	0.30	0.00	0.00	0.02
Avg-	0.00	0.00	0.03	0.26	0.57	0.00	0.00	0.20
Bad	0.00	0.01	0.06	0.47	0.84	0.00	0.00	0.39
								0.73

Source: Fragility Curve for typical smaller bridges.

to the approach spans. In other words, the approach spans dominated the damage estimates.

Two types of damages were considered: severe structural damage or collapse of structures carrying a route or a section of highway, and the collapse of structures passing over a route or section of highway. Either event would render the section of highway impassable at the point at which it occurred. However, a distinction should be made between roadways or railways that are blocked because of fallen overhead structures and roadways or railways that are made impassable because of the collapse of support structures. In general, the former can be cleared within a few days of their collapse, although the clearing of this debris would probably require more than one or two days since heavy machinery must be mobilized to the site and the fallen spans or pieces of overhead structures must be broken up before they can be removed from the roadway. In comparison, the replacement period for collapsed support structures would usually be several months. The analyses were limited to the sections of major routes for which bridge data were available. They did not include possible detours through lower category parallel routes. In some cases, even though a major route might be impassable, detours via slower or lower capacity minor routes might still be available.

The results of the analyses indicate the probability of survival for each one of the major route highway and railway sections which were included in the analysis. The results are keyed to a network diagram for each city. Two different probabilities of survival are shown, one assuming complete independence of the damages to the bridges in each section and one assuming complete dependence of the damages. These can be taken as lower and upper limits, respectively, on the probability of survival; in actual fact the events would generally be partially but not completely independent. More detail on the meaning and use of the survival probabilities is given in the section on the results of the analysis.

II.D.4. DAMAGE ASSESSMENT METHODOLOGY FOR UTILITY SYSTEMS (Electric, Water, Gas, Sewer)

General and city-specific aspects for each of these utility systems were identified and studied under the assumed conditions of ground shaking, soils failure and existing system structural features. A "weak link" vulnerability assessment was performed to identify and acknowledge the importance of utility-and system-specific failure prone elements. For example, the electric substation components (notably among these being porcelain insulators) typically found in the study area are particularly vulnerable to earthquake induced failure. Loss of these stations cripples or inactivates an electric system. These known weak links, added to inevitable additional damage to local distribution networks, generating facilities and overland long distance transmission lines, allows for better assessment of post-earthquake system availability.

A weak link for some water systems is their reliance upon (electrically driven) pumps to provide pressure in the distribution system. Loss of electric power automatically inactivates such a system until standby power (if available) is connected or regular power is reestablished. Thus, even if the distribution piping system survived in good condition (a relatively unlikely event for most of the project cities) water supplied by such a system would be unavailable immediately following a general post-earthquake loss of electric power.

Fragility curve application was then performed upon those utility system structures which were identified and surveyed by project teams in the six cities. Such structures included electric substations, water and sewage treatment plants and storage tanks, elevated and non-elevated. The findings of the "weak-link" system-specific analyses were

combined with those from the fragility analysis to predict the availability of a given utility system.

This method of examining utility systems was applied to all four basic utility types for the six project cities. The results of these analyses are presented both in the general discussion of project results, Section III.B., Public Utilities, and in the individual presentations of results for the six project cities.

Damage Assessments for River Ports

Available information describing river port facilities in the project cities was assembled and evaluated with respect to their availability following the CUSEPP planning earthquake. A key factor in the damage which these facilities can be expected to sustain is their location; i.e., they are located along the bank areas of rivers. Soil and associated foundation conditions in these regions are considered to be poor, compared to those which may prevail elsewhere in a project city. Such soil is likely, due to its type and high degree of saturation, to be prone to liquefaction, differential settling, slumping and sliding. These factors, combined with fragility curve analysis of the structures present, were used to assess the damage to and availability of these potentially important transportation links.

A detailed discussion of these facilities is found in the general part of Section III; City - specific discussions follow in their appropriate sub-parts of Section III.

Damage Assessments to Airports

A combination of fragility curve application and system-specific expertise were used to assess availability of major airport facilities serving the six CUSEPP cities. Minor airports, though addressed in the general discussions portion of Section III, were not investigated in detail.

II.E. Population Effects

1. General

This portion of the discussion of methodologies will address those techniques used to assess casualties and displacement of people. The estimation of casualties resulting from damage to structures, as previously stated, relies heavily upon fragility curve methodology to predict probable damage states for occupied. Estimation of the numbers of persons displaced due to flooding similarly used fragility methods for earthen impounding structures. Assessments of the potential for large flood and conflagrations relied upon overall knowledge of the circumstances prevailing in the project cities.

II.E.2.

II.E.2. Casualty Estimation Methodology

Earthquake casualties result from the collapse of buildings, from falling objects such as parapets and external masonry, or from heart attacks, accidents and other related incidents that occur in the panic and confusion that is produced by earthquakes. In general, the number of casualties produced by earthquakes will depend on population density, building construction types and earthquake intensity. In this century the casualties produced by earthquakes in the U.S. of intensity IX and above have produced deaths ranging from 10 to 500 persons per 100,000 population, depending on the particular circumstances in each case. Eliminating the extreme cases, the range generally falls between 20 and 120 dead per 100,000 population. These figures provide an overall guide for estimating the casualties from future earthquakes.

For this project, the casualties were estimated for the six cities on the basis of census tracts. This was done to indicate to planners where casualties and associated problems are most likely to occur. A large amount of uncertainty is associated with the estimate for each individual tract. However, when the tracts are aggregated into larger areas, the uncertainty is reduced, and the combined estimates become more reliable.

The methodology used to estimate the casualties for the earthquake postulated in this project takes into account the population, the employment and the probable damages to buildings of each type of construction in each tract, to the extent that these data were available. The methodology varied slightly from city to city, depending on the specific data available, although a similar overall approach was taken in each case, with the exceptions being made primarily to adjust for missing data.

Casualties were estimated for two periods (i.e., during a typical day, early morning or night time, say 2 o'clock in the morning), and "at work or

school" (i.e., early afternoon, say at 2 o'clock)*. Early afternoon finds school children in relatively unsafe school buildings. In general, school buildings are considerably less safe than the homes where the school children are expected to be in the late afternoon.

a. Night Time or Early Morning ("At Home") Casualties

It is assumed that most of these casualties will occur in residences. Four basic elements of data were used for determining these casualties: population, the number of housing units, the number of single family residential structures, and the number of multi-family residential structures in each census tract. The first two were obtained from 1980 Census data and the latter two were provided in the FEMA survey. From this data an average number of persons per single family structure and an average number of persons per multi-family structure were estimated for each census tract.

Casualties were estimated for each type of structure: for wood frame single family and wood frame multi-family structures, and for other types of multi-family structures. The FEMA survey data indicated that almost all single family residential structures were of this type of wood frame construction. Casualties in wood frame dwellings were based on the number of those dwellings expected to suffer either severe structural damage or collapse derived from the fragility curve methodology described above. For other than wood frame dwellings (for bearing wall or shear wall structures for example), the expected number of collapses was used. (The number of structures with severe structural damage was used in addition to the number of collapses of wood frame buildings because relatively few collapses are expected to occur).

*Previous studies for other areas have also estimated late afternoon (such as 4:30 p.m.) casualties and have found those in some areas to be greater than the early afternoon casualties.

To determine the expected deaths and injuries, casualty rates were estimated for wood frame structures and for other types of structures (predominately masonry bearing wall or shear wall construction). These casualty rates were expressed as the percentage of the occupants of damaged or collapsed buildings expected to be killed or injured seriously enough to require more than cursory medical treatment. In the case of the wood frame structures, the number of deaths was estimated at 1% of the occupants of severely damaged and collapsed buildings and the number of injuries at 5%. For the other type of structures, deaths and injuries were estimated at 2% and 8% of the occupants, respectively. The higher rates were used for the non-wood frame structures because of their generally greater weight and, therefore, greater likelihood of incurring casualties given that a collapse occurs.

The casualty rates were developed and adjusted through a process of calibration which compared the predicted casualties with casualties experienced in other earthquakes and with estimates made in previous studies of other areas. The total casualties in each census were determined for each type of structure by multiplying the average number of persons per structure by the expected number of severely damaged or collapsed structures and then multiplying this product by the casualty rate for the occupants of collapsed structures.

A small number of night time casualties can also be expected to occur in non-residential buildings such as hospitals, hotels and commercial or industrial buildings with night workers. Except for the hospital casualties these were estimated at 5% of the expected daytime casualties in these structures, as described below. The night time hospital casualties were estimated by applying the procedure described above for non-wood frame structures to the average night time population of the hospitals.

b. Early Afternoon ("At Work and School") Casualties

Early afternoon casualties were assumed to be produced by failures of three categories of structures: residential, non-residential, (commercial, public non-educational and industrial buildings), and certain types of critical facilities, including schools and hospitals.

The residential early afternoon casualties were derived from the estimates of the night time residential casualties. The night time casualties in each census tract were reduced by the overall city average of the population of the city employed or enrolled in school as a percentage of the total population. In general, according to Census data, between sixty and seventy percent of the population was estimated to be away from home in the early afternoon period, depending on the city. The percentage reaches 70% for Memphis, whereas for Evansville and Paducah it was estimated at around 60%. The residential early afternoon casualties were therefore calculated at 30% to 40% of the nighttime residential casualties in each tract.

The estimation of casualties in the commercial, public non-educational and industrial buildings was based on employment data. The number of jobs, or the number of people working, in each census tract was determined from whatever data sources were available. In some cases this information was obtained from transportation studies which provided information either by tract or by smaller origin and destination zone. In other cases the total employment for the city was distributed among the census tracts on the basis of the number of floors of commercial, public non-educational and industrial buildings in the tract. This procedure was used only if no other information was available. In general, the size of the buildings was not available in the data provided by FEMA; the number of floors gave the next best basis for distributing total employment among the tracts. In the case of Memphis, for example, the

employment in each of 15 planning districts was available from the Memphis Transportation Study; the employment in each census tract in each planning district was estimated on the basis of the number of building floors in each tract within each district.

The expected casualties in the non-residential structures were estimated following procedures similar to that described above for the residential casualties. For the commercial and industrial buildings, the average number of employed persons per structure (for all structures) was multiplied by the number of collapsed structures (and, in the case of wood frame buildings, severely damaged structures) and the appropriate casualty rate for occupants of the damaged buildings to get the expected number of deaths and injuries in each tract. As before, the average casualty rates used were 1% deaths and 5% injuries in wood frame structures and 2% deaths and 8% injuries in other types of construction. The numbers of collapsed and severely damaged structures were obtained by applying the fragility curves to the building inventories in each census tract.

For schools, universities and hospitals, instead of calculating an average number of occupants per structure, the total number of occupants in each type of structure in each census tract was determined, and the casualties estimated by multiplying this total number of occupants by the probability of collapse (or of severe structural damage, for the wood frame buildings) obtained from the appropriate fragility curve and the death or injury rate for occupants of collapsed structures. The results were summed for all structure types to get the total deaths and injuries in each tract. When data by tract were not available, the school and hospital casualties were calculated for the city as a whole.

c. General Comments on the Methodology

As a general comment on the methodology developed for casualty estimation, it must be recognized that adequate historical data which would permit an empirical determination of casualty rates for occupants of different types of collapsed buildings are not available. The casualty rates used in this analysis were estimated on the basis of professional judgement and were verified by comparing the results of the analysis (in terms of deaths and injuries per 100,000 population) with casualties produced by U.S. earthquakes in the past. In general, the results are reasonably consistent with these casualties, after taking into account the particular circumstances in each case. This is discussed in detail below along with the presentation of the results.

The objective of developing the methodology was to provide a systematic approach which would be capable of explicitly taking into account differences in earthquake intensity, construction type and population factors. It was also desired to develop a technique that could provide a logical and rational explanation of the expected consequences of the postulated earthquake.

The casualty estimates developed in this study include only those casualties which would be immediately related to the postulated earthquake. They do not include those which could result from extraordinary secondary events such as conflagration or heavy flooding. In any case, such events as these would probably increase injuries more than deaths. Exactly how much of an increase would depend on the magnitude of the secondary event.

The casualty estimates have been based generally on 1980 population and employment data. Within the uncertainty of the estimates, these can be considered to be valid also for 1983. However, to estimate casualties in future years, the expected growth rate of the population in each city should be used as a basis for projecting the 1980 casualties.

II. E. 3. Damage to Dams and Levees

The failure of earthen structures designed to retain or impound a body of water, i.e. earthen dams and levees, (the characteristic construction type in this region) is of interest in a study of this type for several reasons. The most important and immediate is end danger posed to susceptible population from sudden flooding. Flooding also complicates relief efforts, and loss of a reservoir can mean the loss of part or all of a cities' water supply.

Fragility analysis was used in combination with knowledge and evaluation of type-specific factors to estimate failure potential for these earthen structures. Separate approaches were used for the two categories. For major earthen dams in or near enough to a project city to be of concern, the fragility curve application was primarily used. These structures are usually reasonably well-engineered (though usually not including provisions for seismic resistance) and the prediction of their behavior with this methodology is appropriate. Dams which were likely to sustain "severe-" or "collapse-" level damage of concern. A dam experiencing "severe" damages would dictate immediate action to alleviate a threat to downstream person and property. Collapse-level damage is self explanatory; earthen dams in the study area, even under strong ground shaking, are not likely to suffer collapse-level damage.

Levees along or near major streams, while also generally well-engineered (though similarly often without seismic considerations) are felt to be more prone to allowing water release than are dams. This is due to the generally great length of these facilities and the generally variable and poor-behaving soil where they are built. These factors were combined to give the conclusion that levees in the project

cities would be damaged somewhere along their length to the extent that flooding would occur behind them. The flooding was presumed to take place with water levels in the river or stream at the 100 year flood elevation; thus, areas inundated by a flood of this elevation were evaluated. Individuals living in flooded areas were presumed to be displaced and to require shelter

II. E. 4 Persons Requiring Shelter.

Estimates of the numbers of persons likely to require shelter in the six project cities as a result of the effects of an occurrence of the project earthquake were derived from two sources. Persons displaced due to flooding of residential areas comprised the first group. As stated in the previous section, persons living in inundated areas were presumed to require re-location and shelter.

The second source of persons needing shelter ^{was} ~~uses~~ damage to residential structures. Single and multi-family residences which were likely to sustain moderate or greater damage were considered to be uninhabitable, at least in the short term. Inspection for safety and expedient repair could render some of these residential structures useable after a period of time. Therefore, persons residing in structures estimate^d to sustain moderate or greater damage were assumed to require relocations and shelter.

Available Shelter

Many structures with large capacities to house displaced persons will be available following an occurrence of the project earthquake. A large percentage of those will require safety inspections by competent individuals prior to such use. Available floor space in a safe building, however, is not the only criterion for sheltering persons for even a short time. Sanitary and eating facilities, among others, should be available. From the information collected during the project, school structures were the only structure ~~dated~~ subset which were likely to have the appropriate facilities available. The use of schools has an additional advantage in that many or most are controlled by governmental agencies and thus may be made available promptly for general disaster

relief usage. School structures are generally the first category of buildings to be selected by the Red Cross for immediate shelter of large number of persons. School structures which were estimated to sustain less than moderate damage were assumed to be potentially available for shelters.

II. E. 5. Large Fires/Conflagrations

Due to numerous undefined and uncertain aspects of this topic, it was not possible to make actual estimates of locations of and persons affected by large fires or conflagrations. Certainly many factors favoring large fires will be present following an occurrence of the CUSEPP earthquake. Among these are lack of water and needed equipment to fight fires, sources of ignition such as rupture gas distribution pipes or chemical spills, possible highwinds, as well as many other miscellaneous contributors. Conversely, construction types and densities would argue against widespread, huge fires. The approach taken for this project is that very large fires, engulfing major portions of urban area are unlikely. Smaller "group" fires, involving several buildings are probable; some authorities would term these fires "conflagrations". Of course, any storage point of flammable materials is a potential site for a serious fire. These would often be confined to the immediate vicinity of the fuel source. A detailed discussion is found in the general section of Section III.

SECTION III
EFFECTS UPON SIX PROJECT CITIES

A. Introduction

This section presents and discusses the finding developed during the project. General discussions of each project topic area are presented Part B, with individual findings for the six cities being contained in parts C through H. When appropriate, findings and conclusions have been included in the general section (part B), rather than depicting them in the individual discussion section, the sections on the individual cities include maps showing the predicted ground shaking intensities used on the analyses. Maps (figures ____ and ____) depicting ground shaking for the entire CUSEPP region, were shown in Section II.

B. Major Hospitals; General Discussion

The importance of hospital facilities to a city, and the significance of their damage or loss, cannot be over-stated. Hospitals in the six CUSEPP cities, like those in other urban areas, have represented among their numbers all types and varieties of health care facilities. This report studied only major hospitals, i.e. generally those with greater than 100 beds. Of course, these communities also have small, often specialized and usually privately operated, hospitals and clinics. These could make a positive contribution during an emergency, but they constitute only a small percentage of the total available medical and emergency resources.

A major hospital typically encompasses an impressive number of medical services; normally among these ^{are} general medical care, surgery, therapy and rehabilitation, clinical laboratory facilities to provide crucial diagnostic support, X-ray diagnosis equipment, blood banking and emergency and trauma services (with or without hospital-owned ambulances). Many medical centers provide specialized services, for such areas as new-borne care, cancer, childrens care, and research. Several university officials and veterans hospitals are found in the six cities. All hospitals surveyed had some type of emergency electrical sewer system. Those were usually diesel engine powered, though some were fueled with gasoline and a smaller number with natural gas. Those using natural gas as a fuel will almost certainly lose this fuel source, as well as electric power, following the CUSEPP earthquake (see discussion of electric and natural gas utilities, later in this section). Hospitals using natural gas as an emergency fuel should make some provision for alternative fueling. The systems which are served

by the emergency power units vary somewhat among the hospitals surveyed; however, most include at least the following items: blood storage and other crucial refrigeration, emergency surgical lighting, X-ray and other crucial diagnostic equipment, selected clinical lab facilities, ventilation (but usually not air conditioning and heating) may be supplied with separate fuel for heating. The fragility curve analyses of the emergency power units indicate that they can be expected to be available following the predicted levels of ground shaking in the project cities.

Damage to hospitals in the six cities will vary in extent and severity in the same manner as for other damage types. Table _____ gives a summarization of the availability of major hospital facilities, reflected in numbers of available beds and structures. Availability of other hospital services, not addressed elsewhere in this report, can be generally inferred from these availability findings. Specific discussions for each project city are found in the individual city sections.

As can be seen from Table _____, Memphis will be the most adversely impacted by an occurrence of the project earthquake, with Poplar Bluff similarly affected. Little Rock is likely to avoid significant losses and may be able to serve as a focal point for medical assistance following such a disaster.

TABLE _____
Availability of Major Hospital Facilities

City	Major Hospitals Surveyed	Hospital Structures Surveyed	Beds in Structures Surveyed	All Cities		Beds Expected to be Available/Percent	Emergency Power Unit Available
				Hospital Structures Expected to be Available/Percent	Beds Expected to be Available/Percent		
Memphis	13	25	5,711	13 / 51%	2,770 / 49%	Yes	Yes
Little Rock	8	13	3,758	13 / 100%	3,758 / 100%	Yes	Yes
Evansville	4	20	2,242	18 / 90%	2,027 / 90%	Yes	Yes
Paducah	2	7	811	6 / 86%	723 / 89%	Yes	Yes
Carbondale	1	6	200	5 / 83%	187 / 94%	Yes	Yes
Poplar Bluff	4	7	765	4 / 57%	689 / 90%	Yes	Yes
TOTALS	32	78	13,487	59 / 76%	10,154 / 75%	Yes	Yes

III.B.4a.b.

~~III.B.2~~ Casualties of Health Manpower

To estimate the availability of health services personnel after an earthquake, the casualties of doctors and nurses are calculated based on the casualty rate experienced in hospitals, residential and non-residential buildings of individual cities. The number of medical doctors and nurses (both registered and licensed practitioners) for each of the six study cities are estimated based on surveys of local medical facilities, local telephone directories and various health manpower publications.

Among the medical doctors, it is assumed that half of them would be working in hospitals while the other half would have their practices in non-residential buildings (e.g., private offices, clinics, etc.). About 10% of those who work in hospitals are assumed to work during the night shifts. Among the nurses, it is estimated that 90% of them work in hospitals while the remaining 10% work in non-residential buildings (e.g., clinics, nursing homes and doctor's offices). Approximately 50% of them are estimated to work the day-shifts, while 30% would work the evening-shifts and the remaining 20% would be expected to be on-duty during the night time.

The following table tabulates the casualties (both deaths and injuries) for doctors and nurses during day (≈ 2 pm) and night time (≈ 2 am) for each of the six study cities. It also expresses the casualties as a percentage of the total number of doctors or nurses.

Summary of Expected Casualties
for Doctors and Nurses

City	DOCTORS			
	DAY		NIGHT	
	n	% of Total	n	% of Total
Carbondale	0.3	0.4%	0.1	0.1%
Evansville	2.3	0.7	0.3	0.1
Little Rock	0.6	0.1	0	0
Memphis	28.2	2.6	3.7	0.3
Paducah	2.0	1.7	0.6	0.5
Poplar Bluff	0.1	0.2	0.1	0.1

City	NURSES			
	DAY		NIGHT	
	n	% of Total	n	% of Total
Carbondale	0.5	0.1%	0.5	0.1%
Evansville	2.9	0.2	2.0	0.1
Little Rock	0.3	0	0.1	0
Memphis	76.6	1.3	37.7	0.6
Paducah	3.9	0.6	3.6	0.5
Poplar Bluff	0.4	0.2	0.3	0.1

The expected daytime casualties for doctors range from under one for Poplar Bluff, Carbondale, and Little Rock to over 28 for Memphis. The night time casualties for doctors are substantially lower (ranging from zero to four), since residential structures are, in general, less susceptible to earthquake damage. Except for Memphis and Paducah, where hospitals and non-residential structures are relatively more vulnerable to earthquake damage, the casualty rate for doctors is less than 1% for the other four study cities.

A similar trend can be found for nurses casualties in Memphis and Paducah where the rates are higher. In general, the day time casualty rate for nurses is lower than that of the doctors since half of them are expected to be at home (in lower risk structures) while only 5% of the doctors are expected to be at home during the day time. Because of the low casualty rate for doctors (0 to 3%) and nurses (0 to slightly over 1%), it appears that the health manpower following an earthquake in the six study cities would not suffer serious losses.

Blood Banks

Damage to the contents of blood storage facilities is of obvious concern following any serious disaster. These facilities store whole blood, plasma, other blood components, and additional related items. Blood banks are usually present in major hospitals; these major health facilities include at least short-term (i.e., one-two days usage) storage. Non-hospital blood banks may be commercially owned or may be operated by an organization, public or private. All facilities found in major hospitals and the majority of those in other locations have emergency electric generators to maintain refrigeration of blood supplies. Loss of this vital cooling is one disaster-related way in which blood stocks may be lost. Another is direct loss caused by damage to the building itself, or damage to the blood by overturning storage shelves and similar events.

Since non-hospital blood banks may be housed in virtually any type of structure, survival of these supplies is related to survival of the structure. The findings presented in the sections for the individual cities depicts the likelihood of blood and blood components being available following an occurrence of the project's planning earthquake.

Clinical Laboratories

These facilities are mostly found in major hospitals. Larger cities, such as Memphis and Little Rock, have independent laboratories. These facilities are essential for prompt diagnosis of certain illnesses, but play a role of lesser importance following a disaster, with the associated large number of trauma cases, than for everyday, normal conditions. These facilities are very similar to blood banks on their overall availability.

Ambulance Services

Ambulance services are provided in three basic ways: by hospitals, by fire or other emergency services, and by private or commercial interests. Each community is unique, but fire departments dominate in providing this service. Ambulance vehicles are very frequently parked outside of structures, and may be widely dispersed over a city. This ensures a good availability of these vehicles. Their base or "home" structures are vulnerable to damage, and may be of virtually any structural type. These structures contain communication equipment, supplies, and personnel. Their availability is an important aspect of this service.

III. B. 2. a.

~~III.C~~ Demand on Medical Resources

Although the medical resources in the study area will suffer considerable damage, as explained above, they will still be called upon to treat and care for substantial numbers of injured persons. Following are the casualty estimates for each of the six cities in the study area.

C.1 Deaths and Injuries (Excluding Those from Dam Failure)

The expected deaths and serious injuries in the six cities of the study area, determined as explained above in Section II E 1, are summarized in Table III C 1-1.

Except in Little Rock, where intensities of only VI and VIII are expected, the expected night time deaths in the six cities range between 20 and 120 per 100,000 population and the day time deaths between 110 and 400 per 100,000. The higher deaths per 100,000 population are a consequence of higher earthquake intensities and more vulnerable types of construction. As a general case, the night time casualties are relatively low, since the larger residential areas in each city are usually located in the areas of lower intensity, and consist primarily of wood frame structures. On the other hand, expected day time casualties are several times greater than night time casualties because the population moves from the relatively safe residential areas into buildings which are much more vulnerable to earthquake damage (most schools and commercial structures are of bearing wall or shear wall construction) and are often located in areas with greater expected earthquake intensities. Because of their greater weight, these latter buildings are also more liable to produce casualties when they collapse than are the lighter wood frame structures. In the particular case of Paducah, the relatively high expected night time casualties are a consequence primarily of the large number

of non-wood frame multi-family residences which are expected to collapse in that city.

The daytime casualties per 100,000 population are somewhat higher than those estimated for other areas in previous studies. This is primarily a consequence of the types of construction in the six cities (and especially in Memphis), which generally have not been built to the seismic building codes which typically have been used in the areas for which the previous casualty estimates have been prepared (such as San Francisco and Los Angeles). The difference is more noticeable in the day time casualties than in the night time, since in the latter case wood frame dwellings with similar seismic characteristics house most of the people in both the current and the previous study areas.

A breakdown of the expected casualties by population segment is presented in Table III C 1-2. A substantial portion of the daytime casualties can be expected to occur among primary and secondary school children. Most of the school buildings in the study area are of unreinforced bearing wall construction, and the large number of collapses of these structures that are expected to occur will result in considerable deaths and injuries. These are summarized as follows:

<u>City</u>	<u>Total School Casualties</u>		<u>Deaths as a % of Total Daytime Deaths</u>
	<u>Deaths</u>	<u>Injuries</u>	
Carbondale	37	149	45
Evansville	66	265	30
Little Rock	7	28	11
Memphis	594	2376	23
Paducah	21	85	18
Poplar Bluff	15	58	78

As stated above in the discussion of the methodology, the casualty calculations were based on the number of buildings which are expected to suffer severe damage or collapse in each of the six cities. These expected damages are summarized for residential and for commercial and industrial structures in Table III C 1-3. The expected damages to hospitals, schools and universities are discussed in the sections dealing specifically with those types of critical facilities.

TABLE III C 1-1
SUMMARY OF EXPECTED CASUALTIES

City	Study Area Population	Deaths ¹		Injuries ¹		Deaths per 100,000 Population	
		Night	Day	Night	Day	Night	Day
Carbondale	31,670	10	83	40	331	31	261
Evansville	135,950	29	222	119	889	22	163
Little Rock	179,780	3	61	10	245	2	34
Memphis	643,540	359	2,544	1,748	10,242	56	395
Paducah	42,020	50	117	208	471	119	279
Poplar Bluff	17,140	3	19	14	77	17	109
Total	1,050,100	454	3,046	2,139	12,254	247	1,241

¹The numbers are shown as they resulted from the calculations. The results were not rounded because of the differences in the magnitude of the casualties in the various cities. (Rounding Little Rock or Poplar Bluff to the nearest 10, for example, would have produced significant distortions of the results).

TABLE III C 1-2
CASUALTIES IN GENERAL POPULATION,
HOSPITALS AND SCHOOLS

City	Population Segment	Deaths		Injuries	
		Night	Day	Night	Day
Carbondale	General Population	10	25	40	99
	Hospitals	0	0	0	0
	Schools	-	37	-	149
	Universities	-	21	-	83
	Total	<u>10</u>	<u>83</u>	<u>40</u>	<u>331</u>
Evansville	General Pop.	28	154	114	616
	Hospitals	1	2	5	8
	Schools	-	66	-	265
	Universities	-	-	-	-
	Total	<u>29</u>	<u>222</u>	<u>119</u>	<u>889</u>
Little Rock	General Pop.	3	51	10	204
	Hospitals	0	0	0	0
	Schools	-	7	-	28
	Universities	-	3	-	13
	Total	<u>3</u>	<u>61</u>	<u>10</u>	<u>245</u>
Memphis	General Pop.	321	1,761	1,595	7,109
	Hospitals	38	72	153	287
	Schools	-	594	-	2,376
	Universities	-	117	-	469
	Total	<u>359</u>	<u>2,544</u>	<u>1,748</u>	<u>10,241</u>
Paducah	General Pop.	49	93	204	370
	Hospitals	1	1	4	5
	Schools	-	20	-	85
	Universities	-	3	-	11
	Total	<u>50</u>	<u>117</u>	<u>208</u>	<u>471</u>
Poplar Bluff	General Pop.	3	3	12	15
	Hospitals	0	1	2	3
	Schools	-	15	-	59
	Universities	-	-	-	-
	Total	<u>3</u>	<u>19</u>	<u>14</u>	<u>77</u>

TABLE III C 1-3
SUMMARY OF CASUALTY-PRODUCING DAMAGES TO RESIDENTIAL
AND COMMERCIAL/INDUSTRIAL STRUCTURES

City	Total Number of Residential Structures			Number of Damaged Residential Structures ²			Total Number of Commercial, Public Non-Ed. and Industrial Structures		Number of Damaged Commercial, Public Non-Ed. and Industrial Structures	
	Single Family	Multi-Family		Single Family	Multi-Family		Wood Frame	Other	Wood Frame	Other
		Wood Frame	Other		Wood Frame	Other				
Carbondale	7,747		700	25	3	22	452	271	2	43
Evansville	37,336		2,062	56	2	42	403	3,349	1	423
Little Rock	59,002		14,974 ³	1	0 ³	13	482	1,474	0	49
Memphis	140,943		12,805	4,402	444	98	1,589	7,969	54	2,458
Paducah	9,792		1,021	87	6	119	174	1,435	4	365
Poplar Bluff	4,429		1,195	59	23	0	306	220	7	4

¹ Assumed to be almost all wood frame, as indicated in the FEMA Survey data.

² In the case of the wood frame structures, the damaged structures are those suffering severe structural damage or collapse. The damages to the other structures are all collapses.

³ The number of units instead of the number of structures was provided in the survey data.

III. DISPLACED PERSONS AND AVAILABLE SHELTER

Failure of Dams and Levees - Human Aspects

With the possible exception of Paducah, none of the project cities faces life-threatening risk due to the failure of dams and levees. Except for Paducah, none have dams of significance near enough to have an important effect. Poplar Bluff and Carbondale are not endangered in any significant way. Paducah is only a relatively short distance down stream from two large reservoirs, restrained by earthen dams. This situation is discussed in Paducah's individual section.

All cities except Poplar Bluff and Carbondale are subject to flooding due to damage to their levees. The flooding will displace persons, but is not likely to cause significant casualties. Table _____ presents a summary of persons displaced and areas flooded for the four cities subject to this risk. Maps depicting innundated areas of the four project cities subject to flooding are included in the individual city sections.

TABLE _____
Failure of Dams and Levees

<u>City</u>	<u>Persons Likely to be Displaced and Require Shelter</u>
Memphis	1,199
Little Rock	4,707
Evansville	17,497
Paducah	5,254
Total:	28,657

Damage to Residences

Table _____ shows estimates of persons likely to be displaced and require at least short term shelter. Thus information is summarized from tabulations in the individual city sections.

	TABLE Damage To Residences Persons likely to be Displaced and Require Shelter		
	Single Unit	Multi-Unit	
	<u>Residents</u>	<u>Residents</u>	<u>Total</u>
Memphis	159,130	72,550	231,680
Little Rock	1,115	1,325	2,440
Evansville	7,583	3,513	11,095
Paducah	6,318	7,000	13,318
Carbondale	3,003	2,725	5,728
Poplar Bluff	2,443	3,300	5,743
			Total: 270,004

School Structures Available for Shelter

Table _____ presents a summary of school structures likely to be available for shelter. This information is also available in the individual city sections.

Table _____ School Structures Likely to Be Available for Use as Shelters	
Memphis	92
Little Rock	145
Evansville	29
Paducah	5
Carbondale	17
Poplar Bluff	1

III.8.3. Effects on Critical Facilities

A. Public Services and Structures

Fire and Police Services:

These services are vital in any emergency and especially so in one of this magnitude. The damage to structures associated with these services was assessed and availability estimated.

Schools:

School buildings can be important locations for shelter and feeding of those persons displaced by the project earthquake. Buildings available for such usage are tabulated in the preceeding section and in the individual city sections.

B. Communications

Damage to these structures is tabulated in the individual city sections.

C. Transportation Systems

The four basic transportation systems, railroads, highways, river ports and airports, were examined for each of the six project cities, under the assumed conditions of ground shaking and soils failure associated with the project earthquake. General factors and findings will be discussed in this section. The rail and highway analyses will be discussed jointly, as the methodology of analysis for these systems was generally the same. River ports and airports will then be addressed. Specific findings are presented in the individual sections for the project cities.

Railroads and Highways - General Discussion

As discussed previously, the focus of the damage assessment analysis is to develop a probability of survival for sections of the highway and rail networks. These probabilities can be used to plan post-earthquake strategies for the movement of goods and people as well as to allocate pre-quake planning efforts.

Probabilities are defined operationally as the expected relative frequency of various outcomes resulting from an event that repeats many times. A probability of .05 of an outcome means that that outcome is expected to occur 5 times out of 100 opportunities. (Probabilities are described as percentages here to emphasize the relative frequency definition). Although earthquakes are rather rare events for any one place, a history of the survival of different types of structures during earthquakes in many places does allow probability estimates to be made. In actuality, failures may differ substantially from those suggested by this analysis. The probability estimates are most likely to be accurate when they are used in an aggregate sense. Therefore, the statement that

it is likely that 30% of the sections in a city will fail is more likely to be accurate than is the statement that Route US 70 will be closed by an earthquake.

In the traditional use of statistics, a probability criteria is selected for determining whether an outcome is likely or not. Usually if an event has a probability of occurrence of less than 5 times out of 100 it is considered so unlikely that it is assumed that it will not happen. This concept has been used in this damage assessment work. Ideally these calculations would be performed for the entire network to find relative estimates of damage. A desirable output would be a list of likely surviving routes ordered by the probability of their survival. This work did not allow that level of detail; alternatively, the probability of survival of each section is used to predict damages. If the probability of survival was greater than 90%, the section was assumed to survive and no comments were made. A section with a survival probability lower than 90% was considered to be a candidate for failure and the impact of failure is discussed.

Loss of accessibility to a city from a certain spatial direction depends on the relationship of sections in sequence and in parallel. General comments considering these relationships are provided but more detailed analysis should be undertaken for planning work.

Each mode - rail and highway - is discussed for each city. For each city and each mode, a table is presented providing descriptive information about the structures, the earthquake intensities and the probabilities of survival. Four maps for each city are presented - two each for rail and highways. One map for each mode and city has a smaller scale indicating sections in the surrounding area (usually the

county in which the city is located). The second map has a larger scale in order to more clearly identify the sections within the city limits.

Finally, probabilities calculated on the assumption that structures in a section are independently affected are presented as a "worst" case, and as the most reasonable assumption of actual dependency.

Disruption to Rail Systems: Summary

The six project cities can be expected to suffer varying degrees of disruption to their rail systems following an occurrence of the project earthquake. Little Rock would probably suffer no loss in rail accessibility; Evansville would experience little or none. Carbondale could suffer impaired accessibility from the west, while Paducah is most vulnerable to rail losses to the north (crossing the Ohio River) and from the east. The cities likely to suffer great disruption are Poplar Bluff and Memphis. For Poplar Bluff, rail access from all directions is at risk of serious impairment, though not to the extent expected in Memphis, where over 75% of all system sections have less than desirable survival probabilities, and all but one section entering the city are at risk. Memphis is likely to experience significant rail isolation.

Disruption to Highway Systems: Summary

Availability of Major Highway Bridges in General Study Area (i.e. Not Found in Six Cities)

Fourteen major highway structures (bridges) in the region, not associated with the project cities were examined. They are listed below with their survival probabilities:

<u>Route</u>	<u>Description</u>	<u>Survival Probabilities</u>
I-24	Tennessee River	0.78
I-24	Cumberland River	0.70
I-57	Mississippi River	0.78
SR 146	Mississippi River	0.70
SR 56	Ohio River	0.70
US 165	Arkansas River	0.70
US 231	Ohio River	0.70
US 49	Mississippi River	0.70
US 60	Mississippi River	0.78
US 60	Ohio River	0.70
US 68	Cumberland River	0.70
US 68	Tennessee River	0.70
US 79	Arkansas River	0.78
	Wabash River	0.70 to 0.78

These survival probability assessments are sufficiently similar that none can be singled out for special consideration on the basis of survival. However, the impact of the loss of these structures on regional accessibility should be considered in subsequent analyses. It should be noted that all of these structures have survival probabilities well below the 90% criterion, and can be considered prone to failure.

Summary of Disruption for the Six Project Cities

An earthquake would have very little affect on highways into and within Little Rock. Little loss of accessibility could be expected in Carbondale and Evansville. Paducah's highways would suffer some damage but no serious loss of accessibility would result. Poplar Bluff is almost certain to lose some accessibility while Memphis will suffer serious losses into and within the city.

III. B.3.c.3.

RIVER PORTS

The inland waterway system that meanders throughout most of the study area has precipitated much waterfront land development, both port facilities and waterside located production facilities. The port facilities are either private terminals or public terminals. The waterside production facilities are all private and typically have their own private port terminals.

Private port terminals are, of course, designed and operated to meet the unique, particular needs of the shipper or receiver who built them.

Public port terminal, on the other hand, are available to all shippers or receivers. They generally provide docks, wharfs, loading and unloading equipment, warehouses, tank farms and open storage for all types of commodities that move by barge. Most public terminals have railroad and highway connections which permit the direct interchange of freight between barges and land based transportation.

The commodities particularly attracted to inland water-borne transportation are raw materials, moving in large quantities from one stage of production and processing to the next stage. Many heavy, bulky semifinished as well as finished products are also moved by barge. The principal commodities handled on the inland waterway system, as determined by a 1979 Commerce Department study are coal, petroleum and petroleum products, grains, construction materials, and chemicals. These items account for about 75 percent of the total inland traffic by tonnage. Two of the commodity groups, coal and petroleum products, constitute approximately 50 percent of the waterborne traffic in the Mid-America region, with coal alone contributing almost one third of the

total tonnage.

Waterfront development is typically located in the relatively flat land adjacent to the inland waterway system. These sites are frequently in the flood plain of the river and consists of alluvial deposits of the river. The nature of these sites combined with the heavy loading common in waterfront develop creates severe foundation problems. Low bearing strength, differential settlement, and slope instability are often design concerns in these areas. High and frequently fluctuating groundwater levels are also a problem.

During a major earthquake significant destruction can be anticipated in the waterfront development areas. The movement of the earth in combination with the types of soils found in the areas and the typically high groundwater will create severe liquifaction problems. The resulting loss of bearing strength will sever pipelines and conveyors, rupture storage tanks, topple warehouse buildings and dock facilities, crack and displace paved storage areas, and render most other facilities unusable.

Airport Facilities

Within or near the project cities there are a variety of airports, both privately and publicly owned. Normally, private facilities are small, single runway (often turf-surfaced) facilities. They may or may not have lighting and they do not typically have navigation aids. Publicly owned airports range in size and complexity from those equivalent to small private facilities serving general aviation traffic, to those with large multi-directional runway facilities capable of serving commercial air carriers. Airport facilities of the small, non-complex type typically have one hard-surface runway, simple navigation lighting, simple directional navigation aids and visual approach navigation aids. Airport facilities of the more complex type typically have several runways, runway and taxiway edge lighting, complex directional navigation aids, visual, and instrument approach facilities. Two of the project cities, Memphis and Little Rock, have Category II instrument landing systems available at their primary public airports..

Airport facilities are likely to retain partial availability and utility following a major earthquake. Terminal buildings, maintenance structures and aircraft hangers will sustain damage typical for their structural types. Fuel dumps, which are typically steel tanks, may rupture or suffer piping breaks due to loss of bearing strength and differential settlement. Useable portions of runways, taxiways and aprons are likely to be available. These paved surfaces exert very little pressure on the earth in an unloaded state and, therefore, can be expected to survive major ground shaking. Serious liquefaction and differential settlement of the subgrade beneath the pavement can cause

misalignment of these surfaces which could be great enough to prevent their use. Airport navigational lighting systems are comparatively simple and resilient and may survive a major quake. They are, of course, susceptible to electrical distribution system failure, since back-up power is not usually provided. Many navigational aids are sensitive electronic instruments which rely upon careful calibration and adjustment. It is unlikely they would be available for use following an occurrence of the project earthquake.

III.B.3.d. Public Utilities; General

This section of the report will discuss the general aspects of the four main urban utility systems surveyed for this project. These are, electric, water, natural gas and sewage utility systems. Table _____ gives a brief summary of the availability of these systems, following an occurrence of the project earthquake.

TABLE _____
Availability of Utility Systems
All Cities

<u>City</u>	<u>Electric</u>	<u>Water</u>	<u>Gas</u>	<u>Sewer</u>
Memphis	U	U	U	M*
Little Rock	U*	A	M*	A
Evansville	U	U	U	U
Paducah	U	U	U	U
Carbondale	U	U	U	U
Poplar Bluff	U	U	U	U

U - System likely to be unavailable.

M - System may be available.

A - System likely to be available.

* - Limited and/or modified use possible.

III.B.3 d.1. Damage to Electric Utilities

Substation equipment is usually positioned and held in place by gravity, not securely fastened or bolted down. Massive transformers, voltage regulators, structures, racks and other substation equipment can often withstand several times their own weight in a vertical direction. However, this same equipment can sometimes withstand very little force in other directions. Horizontal, rotational, as well as vertical forces affect even the strongest structures during an earthquake which can result in severe substation damage. Resultant damage due to a severe earthquake may include: Slab (pedestal) mounted transformers and voltage regulators inadequately secured can be expected to "slide" or "bounce" off pedestals causing major damage to bushings, lightning arrestors, cooling coils, internal parts, control cables and interconnecting buses. Internal coils and parts generally have poor lateral support. Unrestrained substation batteries racks may collapse resulting in battery damage, rack damage and interconnections may fail due to insufficient slack. Poor weld penetration may result in failure of equipment support, causing equipment damage. Also, welds designed to resist wind loading alone will probably be inadequate. Motion of control (relay) cabinets may result in loss of functions, unsecured switchgear may cause damage to connections to the equipment. Platform mounted equipment may tip over snapping conductors, breaking insulators and spilling oil which could contain PCB material and could cause fires. Porcelain lightning arrestors, large power circuit breakers and

disconnect switch assemblies are highly susceptible to failure. For 161 kV and larger substations, these are probably the most susceptible of all equipment. Pressure relays will be activated by sudden oil surges causing the equipment to trip off the line. Inadvertent operation of relays will also cause line tripping. Circuit breakers can trip or close incorrectly. Equipment will disconnect from structures, or the structure itself will deform to the point where the sectionalizing device can no longer function correctly. Conductors will become entangled or wrapped on adjacent conductors on power line spans.

No attempt is made to estimate the damage that could occur on distribution feeders leaving the substation. However, structural damage will occur to pole and pole line hardware. Faulted sections of the distribution system should be tripped out of service by sectionalizing devices.

Outage time for each electric system will depend on the extent of damage, work crews available, construction equipment, road access to substation, ability of transmission interconnection to restore service back to substations, access to a mobile spare or spare transformer, transportation of spare, or whether a new transformer needs to be purchased. Loss of transformers can cause major long-term disruption of power since they can not be bypassed as can some other damaged substation equipment. It must be remembered that, except for fringe damage areas, generally no assistance (Manpower or equipment) can be expected from neighboring utilities, as they will be experiencing equivalent difficulties. Outage time can range from a few hours to a few months.

III. B.3 d.2. Water Systems

Water Source

In most cases, raw water is pumped from the source to the water treatment facilities. If a major earthquake resulted in the loss of electrical power, most cities would have no means of obtaining raw water until power was restored unless a source of auxiliary power is available. For cities which obtain their raw water from rivers (Paducah and Evansville - Ohio River, Poplar Bluff - Black River), the only adverse effect associated with the water source is the loss of electricity and subsequent inability to pump water. Cities which take raw water from impoundments (Carbondale and Little Rock) may also lose their entire water supply due to dam or levee failure. Damage to raw water intake structures and raw water pipes connecting sources to treatment plants ^{is a} ~~are~~ further possibilities ^y ~~es~~ for system disruption. Memphis uses groundwater as its source of raw water. In the event of major earth movement, the well pump motors, casings, ^f ~~/~~ foundations and piping could be sheared apart resulting in the loss of the wells.

Water Treatment Facilities

Once the raw water is pumped to the treatment facility, it generally flows by gravity through the unit processes. Treated water is normally stored in underground reservoirs or clearwells and is pumped into the distribution system as needed. Without electrical power, water treatment plants essentially would be inoperable. Chemical feed systems and mixers could not be operated and treated water could not be pumped into the system unless a source of auxiliary power is available. With the occurrence of a major earthquake, the possibility also exists that

the treatment facilities themselves and/or the piping between units would be damaged to such an extent that they could not function. Sedimentation basins, aerator buildings, filter buildings, and pumping stations are all susceptible to earthquake damage.

Storage

With the loss of electrical power, a city's sole source of water would be that which flows into the distribution system by gravity from *elevated* storage tanks and standpipes. Storage tanks at or below ground level which require the use of pumps to transfer water into the distribution system would be inoperable unless auxiliary power is available. In many cases, only one tank has an auxiliary power source so that in the event of a major earthquake potable water would be very scarce. Damage to the water storage tank itself, particularly the elevated type, may render it inoperable. The elevated structure may collapse totally or the riser pipe may be sheared. The loss of an elevated tank in this manner would result in water damage in the immediate vicinity of the tank as it emptied.

Distribution

Even if potable water is available from the storage, broken water mains could prevent delivery to the customers. Water distribution systems are generally composed of cast or ductile iron pipe, concrete pipe, or plastic pipe. Plastic pipe is very flexible and would best withstand the movement associated with the earthquake. Both concrete and iron pipe are rigid and, although these materials can withstand a certain amount of movement, would be more susceptible to cracking and rupture. Pipe joints in water systems are primarily the push-on type. Therefore, even if the pipe itself withstands the quake, the

differential earth movement may cause separation at the joints. In general, it is anticipated that water distribution systems would ~~sustain~~ *experience* major damage and, for the most part, become inoperable during a major earthquake. Repair and replacement of the damaged pipe would be a time consuming and expensive process.

Many cities utilize booster pumping stations to increase flow and pressure to outlying portions of their service areas or to fill elevated storage tanks. With the loss of electrical power these stations would be out of service for some period of time. A major quake could also result in complete destruction of the stations or damage to the piping and pumping equipment which would render them inoperable.

III.B.3.d.3.

NATURAL GAS SYSTEMS - GENERAL

Natural gas transmission systems (intra- and interstate pipeline systems) are constructed almost exclusively with welded steel piping. These systems are generally made up of large diameter (12" through 42") underground piping operating at up to 1,000 psig. Several of these large diameter pipelines pass through or near the cities being considered in this study. These systems transport natural gas from the Gulf of Mexico area to major cities in the North and Northeast.

Failure of a section of interstate pipeline is likely during a major quake. However, these systems generally consist of several parallel piping runs that can easily be isolated. Assuming the failure of a few individual piping sections, the pipeline operators could readily valve off these sections of piping and maintain service to the various distribution systems that they serve. The most severely affected areas from actions of this nature would not be the cities in the immediate quake area, but would be the large load centers in the North and Northeast (New York, Chicago, Detroit, etc.) that depend on these pipelines for gas service. In the event of the loss of sections of piping in the middle of these pipeline systems, service at the outer end of the system would have to be curtailed drastically. Of course, the possibility exists that all large liner serving a region may be broken.

The natural gas distribution systems serving the six (6) cities in question receive natural gas from interstate pipelines reduce the pressure of the gas and distribute this gas to residential, commercial and industrial customers in and around the six cities.

The natural gas distribution systems in these cities include welded steel, cast iron and polyethylene piping. Polyethylene piping

is very flexible and probably would withstand the movement associated with a major quake well. Steel piping has some flexibility and would probably break in a few isolated cases. Cast-iron piping is very brittle and would undoubtedly crack and rupture in many places. Fortunately, much of the cast iron in these natural gas systems is scheduled for replacement during the years ahead. However, there will be some cast-iron gas piping remaining in the ground for at least another ten to fifteen years.

In general natural gas distribution systems would have to close down after a major quake. To repressurize the systems will involve a time consuming process of, (1) shutting off individual services lines, (2) pressurizing a small section of main line piping, (3) repairing any leaks found in that section, (4) reconnecting service piping to occupied buildings, (5) relighting pilot lights of appliances in individual building, and then repeating the entire process over and over as service is gradually restored throughout the systems. In many areas of cast-iron piping the entire main would have to be replaced during this process.

Other than piping, other areas of concern in natural gas systems would be compressor stations on the interstate pipeline systems (Fig. __) and pressure regulator stations in the distribution systems. Taking compressor stations out of service would diminish service to the pipeline's upstream customers. Pressure regulator stations are a critical part of each gas distribution system. While a few of these stations might rupture and release gas to the atmosphere, there should be no major problems arising from these stations.

Natural gas is lighter than air and while some line ruptures and

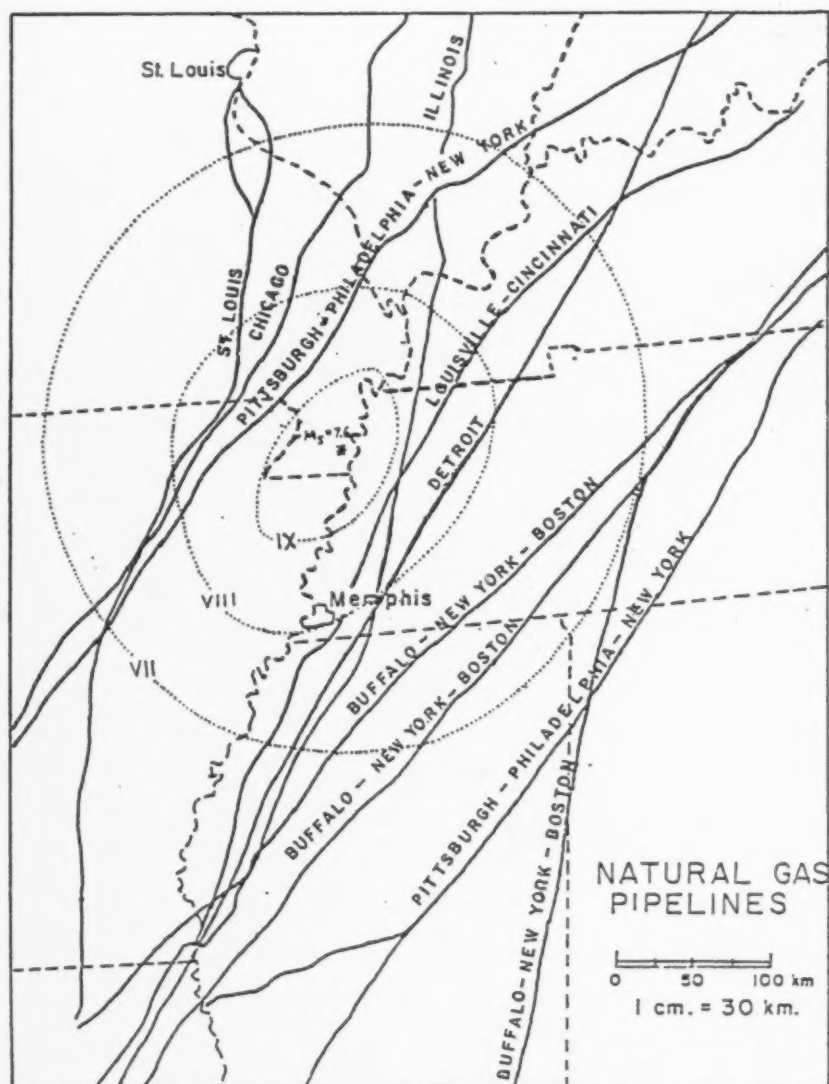


Figure — Location of natural gas pipelines serving the north-central and northeastern United States that pass near the New Madrid fault. Also shown are the VII, VIII and IX generalized isoseismals (dotted lines) for an $M_s = 7.6$ earthquake assumed to occur in the southeast part of the Missouri bootheel. There is enough strain presently stored up along the New Madrid fault to cause such an earthquake, if it were to happen right now. For poor soil conditions, add 1 to 2 units to the intensity value shown in the figure. For outcropping hard rock, subtract 1 or 2 units from the intensity value shown in the figure.

leakage would occur following a quake, most of the leaking gas would simply diffuse into the atmosphere.

The time estimates made for system repair and restoration presume the existence of necessary crews, equipment and replacement parts.

WASTEWATER SYSTEMSPOTENTIAL ADVERSE EFFECTS OF A MAJOR EARTHQUAKE

The wastewater system for a city consists of a collection system and a treatment system. The collection system generally is made up of a network of pipe and lift stations. The wastewater treatment plant (WWTP) usually includes a number of processes which remove solids, Biochemical Oxygen Demand (BOD), and other pollutants from the wastewater.

Generally, wastewater is transported through the collection system to an influent pumping station at the WWTP. The wastewater is pumped into the first treatment unit and from there flows through the system by gravity. With the occurrence of a major earthquake it is assumed that electrical power will be lost for a period of time and that the natural gas distribution system will be shut down. Under these circumstances, the influent pumping station will be inoperable unless auxiliary power is available. Generally, a method of bypassing the wastewater treatment plant is available. Although discharging untreated wastewater is not desirable, the primary purpose of the wastewater system during an earthquake will be to transport the wastewater out of the populated area to minimize the health hazards. In this case, actual treatment of the wastewater is secondary in importance. Significant earth movement also could result in extensive damage to the treatment facilities and/or the piping between units. In this case treatment would be impossible.

Carbondale, Evansville, Little Rock, Memphis and Paducah all have secondary wastewater treatment facilities. The activated sludge process generally consists of grit removal, clarification, aeration,

chlorination, and sludge handling. The treatment units and their corresponding equipment, blowers, pumps, controls, etc., are all susceptible to earthquake damage. Poplar Bluff has three lagoons which require little operating equipment and could continue treatment provided that the wastewater could be transported to them. A major quake could damage or destroy the lagoon levees in which case the treatment system would be lost.

Without electrical power, the wastewater lift stations, which are dispersed throughout each city's collection system, would not operate. Often these stations have bypass facilities which would serve the purpose of removing wastewater from the populated areas. Structural damage to a station building or damage to the pumping equipment^{also} would render the lift station inoperable.

The sewer network operates by gravity flow of the wastewater in the pipes. The most common pipe materials in the six cities surveyed for this study are concrete and clay. Plastic pipe also is used, although not as extensively. Iron pipe is used in special cases such as stream crossings. Force mains are concrete, iron, or plastic. Plastic pipe is flexible and would best withstand the movement associated with an earthquake. Concrete, clay, and iron pipe are rigid and, although these materials can withstand a certain amount of movement, are more susceptible to cracking and rupture. Pipe joints in sewer systems are primarily the push on type. Therefore, even if the pipe itself withstands the earthquake, the differential earth movement may cause

separation at the joints. It is anticipated that even if the WWTP is inoperable and some sewers collapse or are blocked, the remaining sewers and manholes can be used for wastewater storage for some period of time. Under the circumstances of disaster caused by a major earthquake, the storm sewer system could be used to transport wastewater in those cities which have separate storm and sanitary systems.

III.B.4

Large Fires/Conflagrations

Due to numerous undefined and uncertain aspects of this topic, it was not possible to make actual estimates of locations of and persons affected by large fires or conflagrations. Certainly many factors favoring large fires will be present following an occurrence of the CUSEPP earthquake. Among these are lack of water and needed equipment to fight fires, sources of ignition such as rupture gas distribution pipes or chemical spills, possible highwinds, as well as many other miscellaneous contributors. Conversely, construction types and densities would argue against widespread, huge fires. The approach taken for this project is that very large fires, engulfing major portions of urban area are unlikely. Smaller "group" fires, involving several buildings are probable; some authorities would term these fires "conflagrations". Of course, any storage point of flammable materials is a potential site for a serious fire. These would often be confined to the immediate vicinity of the fuel source.

III.C. Memphis; General

The City of Memphis is located in extreme southwest Tennessee, on the eastern bank of the Mississippi River. With a 1980 population of slightly more than 646,000 persons, it is the most populous of the six CUSEPP cities. Memphis is a major regional and national center for all transportation modes, for commerce, and health services.

Physiographic Description (from Hopper et al, 1983, CUSEPP

Report #82-3):

Memphis is situated in the Coastal Plain Province along the border between the East Gulf Coastal Plain and the Mississippi Alluvial Plain. The locally steep bluffs adjacent to the Mississippi River along the west edge of the city are 60 to 100 feet (18 to 30 m) high. Most of the city is located south of Wolf River and north of Nonconnah Creek, an area of low topographic relief.

Figure _____ depicts the hypothetical ground shaking intensities expected for Memphis. These Modified Mercalli Intensities (described in Section II, Methodology) were used to assess damage and disruption to structures and facilities in the city. These strong hypothetical ground motions are responsible for the extensive damage and casualties which are expected to occur in Memphis, should there be an occurrence of the CUSEPP planning earthquake.

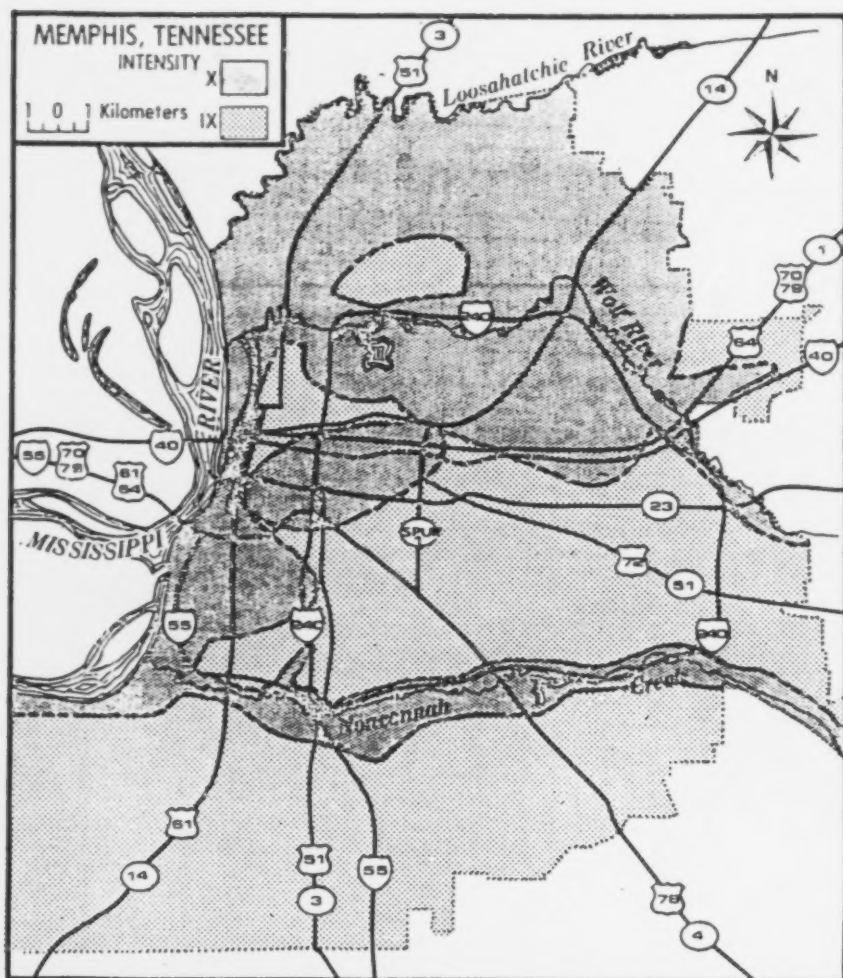


Figure ____ Hypothetical intensity map for Memphis, Tennessee. For an earthquake near the south end of the New Madrid seismic zone, intensities projected for Memphis are: X in the alluvial valleys and in the areas found by Sharma and Kovacs (1980) to have high amplification factors (figure 20) or to be susceptible to liquefaction (figure 19), and IX in the rest of the city. For an earthquake near the north end of the New Madrid seismic zone, the intensities at Memphis would be lower.

from: Hopper, et al, 1983 (CVSEPP Report #82-3)

III. C.2. Effects on Medical Resources

Memphis possesses, as does any city, a wide variety of medical services and facilities. Beyond these, this city serves as a major regional medical center, with a large number of major and small hospitals, clinics and similar facilities. These activities have caused considerable health care support and peripheral activities to develop and prosper. The entities surveyed in this project are: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

The City of Memphis serves as a Major regional Medical Care Center, with large university, religious - sponsored and private health care facilities which serve general, speciality and research medical needs. Hospital facilities are distributed throughout the City, with a majority being concentrated within the central city area.

Damage to hospitals in Memphis will be serious, due to the strong ground motion and potentially adverse soil conditions in the region. Of the twenty four major structures associated with the thirteen major hospitals surveyed, only half (50%) are likely to be available following the project earthquake. The beds associated with these hospitals, 5711, constitute 86 percent of all hospital beds in Shelby County, where Memphis is located. The remaining beds are distributed among other, small hospitals in the area. Of the beds located in the structures of the 13 surveyed hospitals, 2770, or 49 percent, are expected to be available. Emergency power units serving the surviving hospital structures is also expected to be available. Table _____ presents these findings.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Memphis, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE _____
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
13	25	5711	13 / 51%	2770 / 49%	Yes

III.C.2.c. Blood Banks

Availability of blood storage facilities in ^{Memphis} following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Memphis

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	13	7/54%
Non-Hospital:	<u>6</u>	<u>3/50%</u>
Total	19	10/53%

III.C.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Memphis following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospitals emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Memphis

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	13	7/54%
Other	<u>6</u>	<u>4/67%</u>
Totals	19	11/58%

III.C.2.e. Ambulance Services

The availability of ambulance service structures in Memphis following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Memphis

<u>Number of Structures</u>	<u>Number Expected to</u>
<u>Surveyed</u>	<u>Be Available/Percent</u>
22	11.1/50%

III.C.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

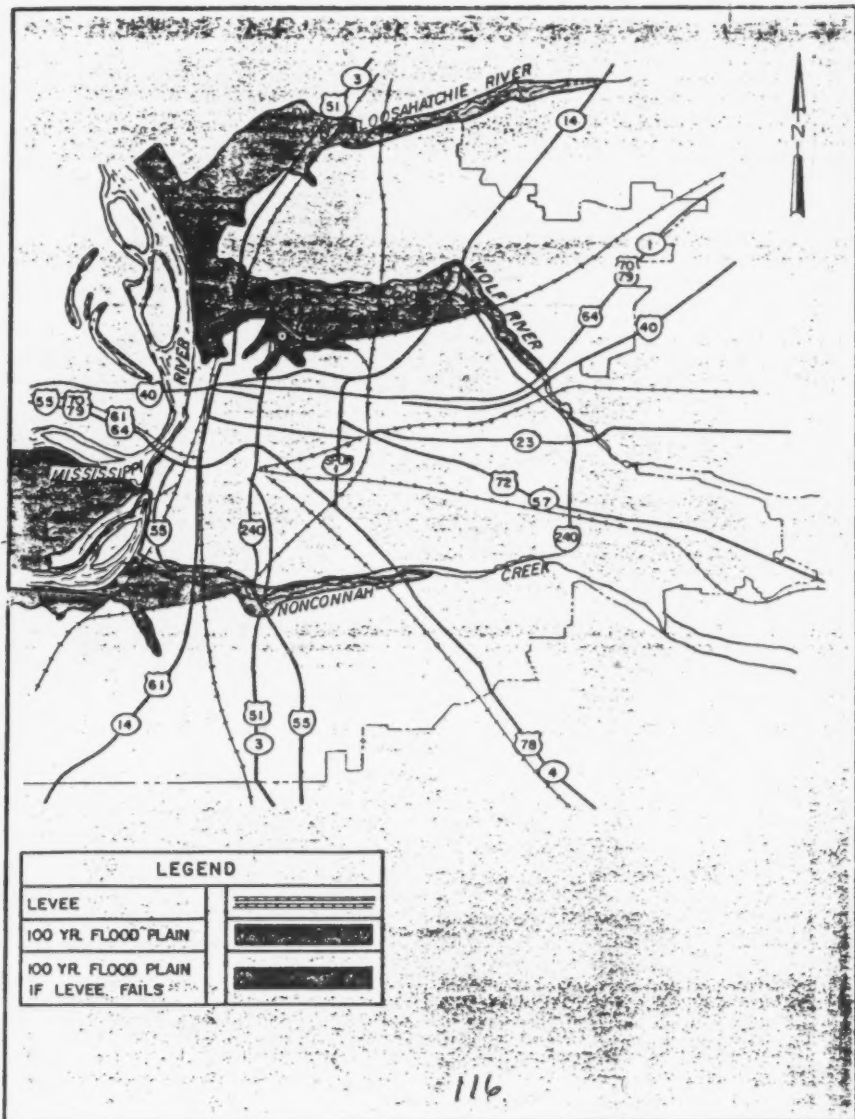
These findings, for the City of Memphis, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

As discussed earlier in Section III, casualties from the failure of dams and levees are not expected to be significant and were not estimated. Persons displaced by flooding are enumerated in Table _____. Figure _____ depicts areas expected to be flooded following levee failure at a time when the water elevations in the Mississippi, and Wolf Rivers and Nonconnah Creek are at the 100 year flood level. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given Table _____, below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE _____
Displaced Persons and Available Shelter
Memphis

Flooding	Damage to Residences		Total	School Structures Available
	Single	Multi-Family		
1,199	159,130	72,550	231,680	32



III.C.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Memphis, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table _____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE _____

Availability of Fire Service Structures

Memphis

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
57	30/53%

2. Police Services

Table _____ shows the expected availability of police service structures in Memphis.

TABLE
Availability of Police Services Structures
Memphis

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
2	1/50%

3. Schools

Table ____ shows the expected availability of school buildings , for use as shelter and for feeding large numbers of persons.

TABLE
Availability of School Structures
For Shelter Purposes
Memphis

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
680	92/14%

b. Communications

Table ____ shows the expected availability of radio, television, and telephone structures in Memphis following the occurrence of the CUSEPP planning earthquake.

TABLE
Availability of Communications Structures
Memphis

	<u>Total Structures</u>	<u>Structures Expected</u>
	<u>Surveyed</u>	<u>To Be Available/Percent</u>
Radio	14	10/71%
Television	10	6/60%
Total	24	16/67%

C. Transportation Systems

1. Railroads

The survival probabilities for key rail system bridges in Memphis are listed in Table _____. Maps of key rail sections are shown in Figures ____ and ____.

A large number of key rail sections (24 of 31) in Memphis have a survival probability of below 90%; with a single exception, every section entering the city limits has a survival probability of less than 75%. While it is not likely that all links would be damaged to the point of being out of service, Memphis could experience a good deal of rail isolation.

The most probable surviving link into the center of the city is Southern Railroad connection from the east, sections 25 and 26.

TABLE III-3-4

PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN MEMPHIS
WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Railroad Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Struct.			Total Independent	Total Dependent
1	ICG-J	1	5	0	X	.64	.78
2	ICG-J	8	0	4	X	.15	.78
4	ICG-J	6	1	3	X	.18	.78
5	ICG-J	1	2	3	IX/X	.49	.70
6	ICG-J	1	1	0	X	.76	.78
7	ICG-J	5	0	1	IX/X	.66	.78
8	ICG-JG	3	2	4	IX/X	.41	.78
9	ICG-JG	15	1	13	IX/X	.05	.58
10	ICG-JY	0	1	2	X	.94	.94
11	ICG-L	4	0	4	IX/X	.20	.58
12	ICG-LNB	2	1	1	IX	.85	.94
13	ICG-LSB	9	0	2	IX/X	.54	.86
14	L&N-B1	5	0	3	IX/X	.18	.58
15	L&N-ML	2	0	5	IX/X	.14	.58
16	L&N-ML	8	0	1	X	.05	.70
17	L&N-ML	7	0	2	IX	.62	.94
18	MOPAC	1	3	0	X	.63	.70
19	MOPAC	4	4	3	X	.19	.70
20	MOPAC	0	13	0	X	.97	.97
21	MOPAC	5	3	1	IX/X	.78	.94
22	MOPAC	2	0	3	IX/X	.76	.89
23	MOPAC	1	0	1	IX	.94	.96
24	MOPAC-D	3	0	6	IX	.54	.80
25	SOUTHERN	2	0	1	IX	.90	.96
26	SOUTHERN	5	0	1	IX	.83	.96

TABLE III-3-4

PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN MEMPHIS (Continued)

Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Structures			Total Independent	Total Dependent
27	STLSF	1	1	0	X	.47	.78
28	STLSF	0	8	3	X	.56	.89
29	STLSF	0	3	0	IX	1.00	1.00
30	STLSF	2	14	8	IX/X	.50	.80
31	STLSF	1	33	0	IX	.74	.74

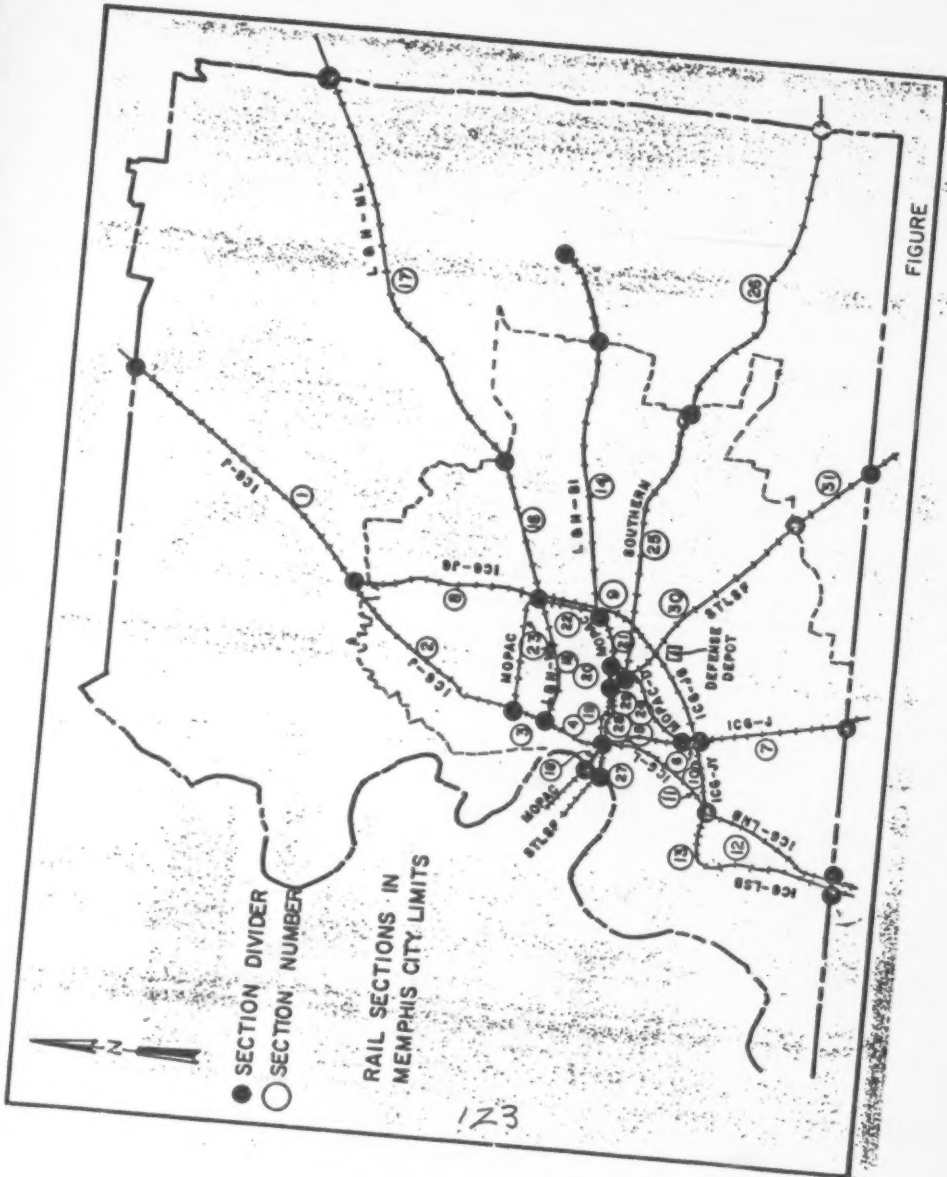
Notes:

1 Probability that the line segment would survive

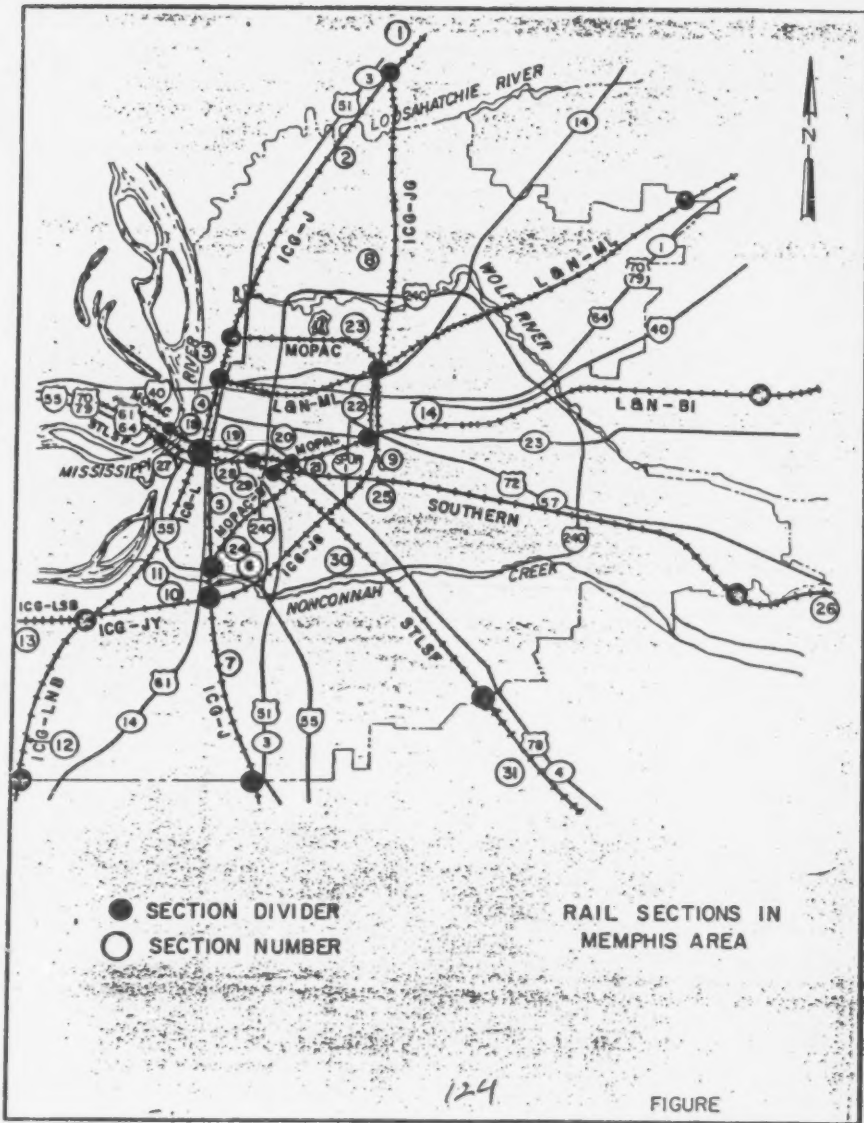
2 Section with no structures:
3 ICG-J

3 3-parallel structure instead of 2

4 Two of them are 3-parallel structures



FIGURE



2. Highways

Table _____ contains the survival probabilities major highway elements in Memphis. Figures ____ and ____ show the Memphis highway network.

Considerable damage to the major highway network in and near Memphis is probable. Although this network is extensive, having 11 points of access into the city limits, the analysis reveals that it is prone to failure. 49 of 62 highway segments have survival probabilities lower than 90% criterion. Loss of road availability within the city itself is probable, as is extensive loss of overall accessibility. A route on US 70 and 72 from the east provides the most probable surviving entrance. All of access routes from the north, west and south are prone to damage; however, it is unlikely that all would be closed due to simultaneous failure.

TABLE III-3-10

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
MEMPHIS WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Route	Number of Structures Supporting Route		Number of Structures Earthquake Over Route Intensity	P (Survival)	
		Single Structures	Pairs of Parallel Structures		Total Independent	Total Dependent
1	I240	0	0	6	.02	.27
2	I240	0	2	2	.21	.29
3	I240	0	4	3	.05	.29
4	I240	0	5	8	.07	.29
5	I240	1	3	4	.02	.27
6	I240	0	1	9	.05	.29
7	I240	1	1	2	.55	.74
8	I240	0	0	4	.07	.27
9	I240	7	1	4	0	.16
10	I240	3	1	2	.02	.16
11	I240	2	1	0	.45	.29
12	I240	1	2	0	.38	.70
13	I240X	1	0	1	.12	.43
14	I40	1	0	0	.43	.43
15	I40	1	0	0	.92	.94
16	I40	1	0	1	0	.16
17	I40	4	1	2	.08	.29
18	I40	3	4	6	.06	.29
19	I40	0	6	4	.65	.88
20	I55	2	4	4	.51	.78
21	I55	2	4	5	.39	.70
22	I55	1	3	0	.04	.29
23	I55	1	4	5	0	.29
24	I55	2	0	10	.03	.16
25	SR83	0	0	2	.79	.89
26	SR83	1	0	1	.92	.94
27	SR83	1	1	0	.05	.16

JLE III-3-10

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
MEMPHIS (Continued)

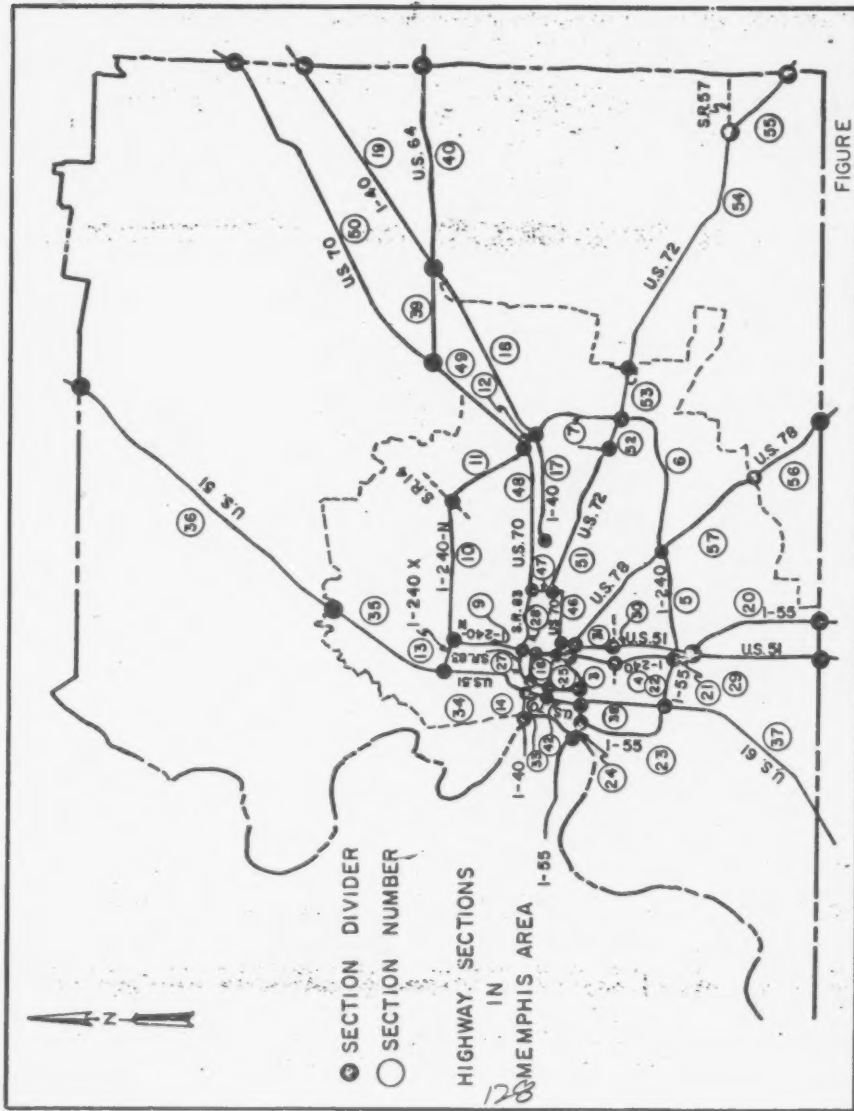
Section ²	Route	Number of Structures Supporting Route		Number of Structures Earthquake Over Route Intensity	P (Survival)	
		Single Structures	Pairs of Parallel Structures		Total Independent	Total Dependent
28	SR83	0	0	1	.89	.89
29	US51	4	0	0	.85	.94
30	US51	7	0	2	.09	.43
31	US51	0	0	2	.96	.98
34	US51	2	0	1	.38	.58
35	US51	4	2	0	.16	.68
36	US51	1	2	0	.39	.68
37	US61	2	1	0	.51	.74
38	US61	5	0	1	.26	.53
39	US64	2	0	2	.12	.43
40	US64	2	0	0	.92	.94
41	US70	0	0	1	.89	.89
42	US70	0	0	1	.89	.89
43	US70	1	0	0	.70	.70
44	US70	1	0	0	.78	.78
46	US70	1	0	0	.74	.74
48	US70	3	0	2	.21	.43
49	US70	2	0	0	.19	.43
50	US70	10	1	0	.27	.74
51	US72	2	0	0	.92	.94
52	US72	0	1	0	.78	.78
54	US72	1	0	0	.98	.98
55	US72	2	0	0	.73	.74
56	US78	2	0	0	.55	.74
57	US78	6	0	0	.07	.16
58	US78	1	1	1	.71	.75
59	US78	0	0	2	.96	.98
60	US78	0	0	2	.79	.89
62	US78	0	0	2	.79	.89

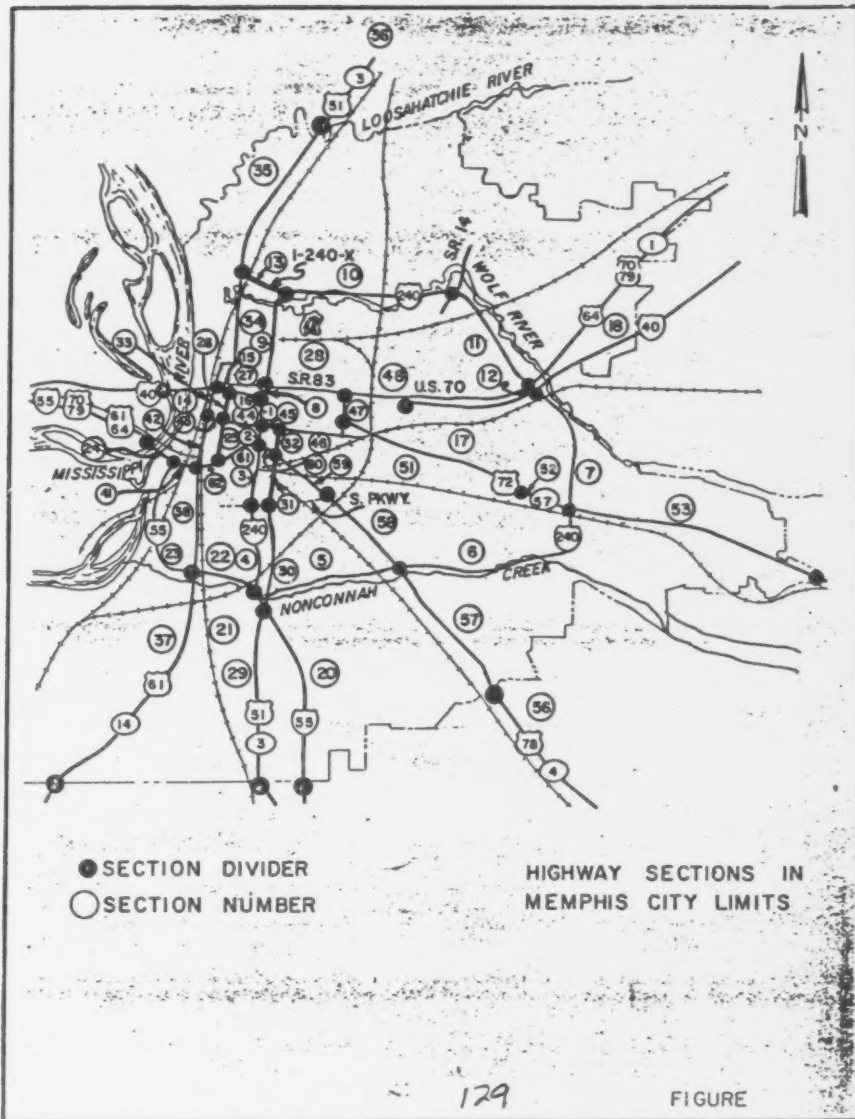
Notes:

1 Probability that the route segment would survive

2 Sections with no structures:

32, 33	US51
45, 47	US70
53	US72
61	US78





3. Docks (River Ports)

Due to the generally unfavorable soil conditions which are typical for the river-bank locations of port and dock facilities, it is expected that these facilities will not be available for use in Memphis following an occurrence of the CUSEPP planning earthquake. Figure ____ shows the location of river port and dock facilities for Memphis.

4. Airports

As discussed in the general section on airports, (Section III.B.3.c.4.) airport runways will ^{generally} be at least partially available for use in Memphis following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for other ^{buildings} in the area of similar structural type. Figure ____ shows the location of major airport facilities for Memphis.

FIGURE _____
Location of River Ports
and
Airports

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d. Public Utilities

1. Electric Utilities

General

Memphis Light, Gas and Water (MLG&W) serves Memphis and vicinity (population 800,000) which purchases its power from TVA. MLG&W has three major interconnections with TVA at 161 kV or higher. These three interconnect supply power to six bulk power stations which supply power to MLG&W subtransmission grid and distribution substation. MLG&W has approximately 3,000 employees and a total of 300 radio equipped vehicles (doesn't include 200 portable transievers). MLG&W has access to TVA's mobile spares, some located in Jackson, Tennessee.

Allen Steam Plant (620 MW capacity) owned by MLG&W is leased to TVA is located near Mississippi River Levee. This is also a 161 kV source for MLG&W, and a 500 kV interconnect with Arkansas Power & Light(AP& L), crossing the Mississippi River, is also located here. Figure _____ shows major elements of the Memphis electric system.

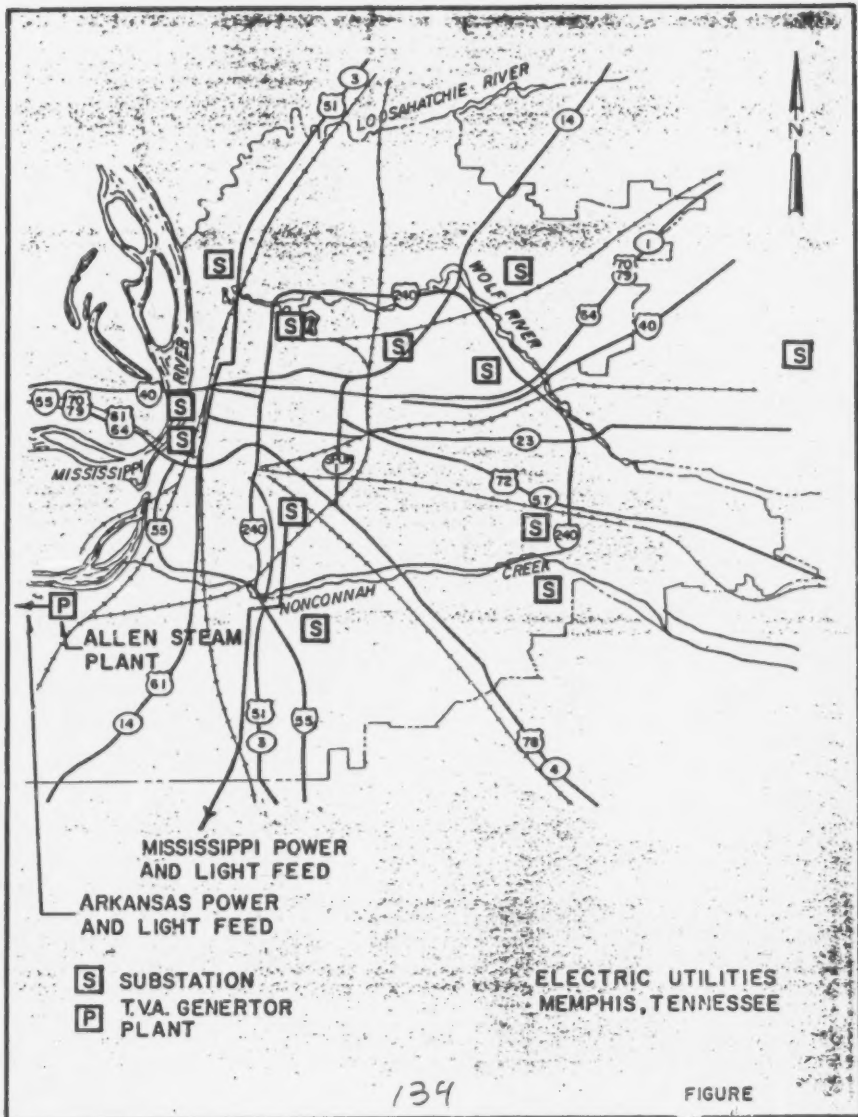
Availability Analysis

Table _____ presents the results of the availability analysis, Fragility techniques and system factors indicate that damage to the system will be extensive and that the system will not be available following an occurrence of the project earthquake. Both the Allen Steam generating plant and the susbtations surveyed would be generally unavailable.

TABLE _____
Availability of Electric Utilities

Memphis

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 11	0/0%	—
Power Plants 1	<u>0/0%</u>	—
TOTAL 12	0/0%	<u>NO</u>



2. Water Utility

General

The Memphis Light, Gas & Water Division (MLG&W) operates the water system for the City of Memphis and much of Shelby County. The source of water for the Memphis area is groundwater taken primarily from the "500 foot sands" of the Claiborne group. The Division operates nine (9) water treatment plants and pumping stations of which seven (7) provide the major portion of the area's water. Generally, the facilities at each station consist of aerators, filters, an underground storage reservoir and pumps. Water is supplied to each treatment facility by 10 to 26 wells. The total treatment capacity at the seven major stations is 195 MGD. Total underground storage at these stations is 94 MG. The well capacity, treatment capacity, and storage capacity for each of the seven major stations is listed in Table ____.

The total elevated storage in the immediate vicinity of Memphis is 2.9 MG. The elevated storage tanks are located primarily on the outskirts of the city limits. The capacities of the elevated tanks are outlined in Table _____. The locations of the water treatment facilities and storage tanks are indicated in Figure _____.

The water distribution system is composed of various types of pipe ranging in size from 6 to 36 inches. For the most part, the pumping stations at the water treatment plants provide adequate pressure in the system. However, there are a few booster pumping stations located in outlying areas.

There is one diesel fueled auxiliary engine for emergency use at the Allen Station. This engine can operate one 15 MGD pump and five wells which pump 10 MGD.

Availability Analysis

Table _____ presents the results of the availability analysis for Memphis' water utility. These findings resulted from a fragility study of the system's structures (i.e. treatment plants, and storage tanks) and system specific factors, such as well and distribution system construction. A major factor was the probable unavailability of electric power. As a result of this analysis, it was concluded that this water system will not be available following the project earthquake. The system may, however, be capable of partial restoration relatively quickly.

Availability AnalysisWater Utility

Memphis

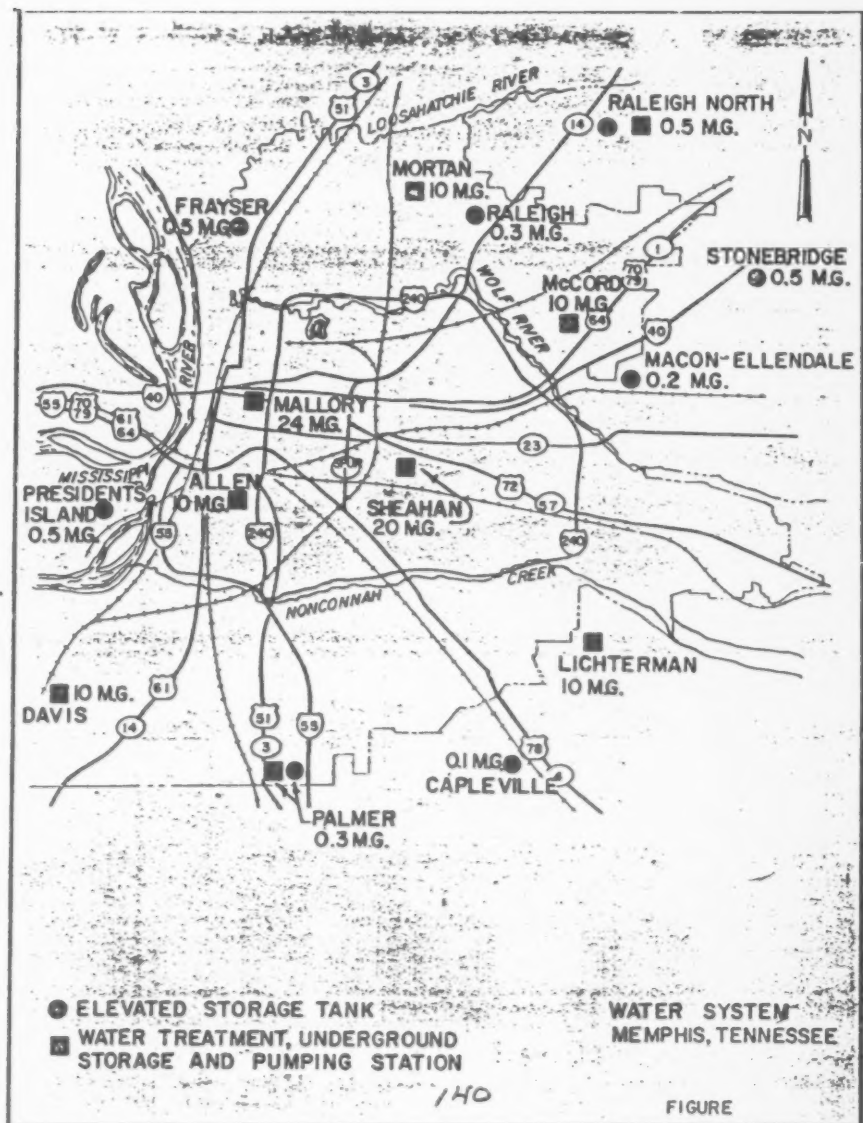
<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>System Availability (Yes/No)</u>
Treatment Plants: 9	1/11%	—
Storage Tanks elevated: 8	4/50%	—
Non-elevated 9	8/89%	—
TOTAL 26	13/50%	NO

TABLE _____
WATER TREATMENT PLANTS
AND PUMPING STATIONS
MEMPHIS, TENNESSEE

<u>Station</u>	<u>No. Wells</u>	<u>Pumping Capacity, MGD</u>	<u>Treatment Capacity, MGD</u>	<u>Storage Capacity, MG</u>
Mallory	26	60	35	24
Sheahan	25	60	35	20
Allen	26	60	35	10
McCord	24	60	30	10
Lichterhan	20	60	30	10
Davis	14	25	15	10
Morton	10	37.5	15	10
TOTAL	145	362.50	195	94

TABLE _____
ELEVATED WATER STORAGE TANKS
MEMPHIS, TENNESSEE

<u>Storage Tank</u>	<u>Capacity, gallons</u>
Presidents Island	500,000
Frayser	500,000
Raleigh North	500,000
Raleigh South	300,000
Stonebridge	500,000
Macon-Ellendale	200,000
Palmer	300,000
Capleville	100,000
TOTAL	2,900,000



3. Natural Gas Utility

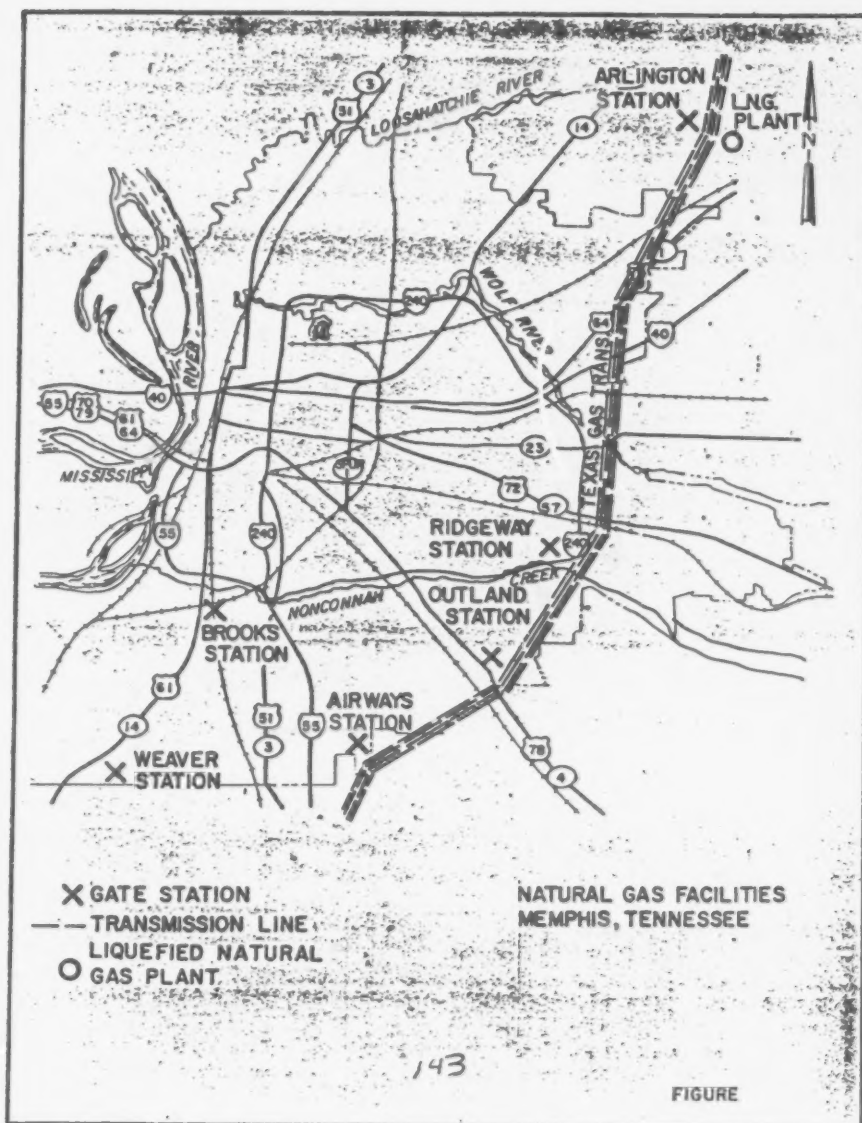
The natural gas system of Memphis, Tennessee is municipally owned and operated. The system has six (6) purchase points and buys it's gas from Texas Gas Transmission Company. There is one LNG plant in the system that stores twelve million six hundred thousand (12,600,000) gallons of liquid natural gas. Two thousand eight hundred forty one (2,841) miles of piping make up the system, of which two thousand three hundred ninety-three (2,393) miles is steel, three hundred sixty (360) miles cast iron, and the remaining eighty-eight (88) miles plastic.

The LNG plant is designed for some seismic resistance. Due to its relative isolation, this plant is not a potential hazard to the community at large. The cast-iron piping in the Memphis system would crack and rupture in many places in the event of even moderate earth movements in the area. Falling buildings and debris during a major quake would also rupture many natural gas service lines forcing authorities to shut down the entire system.

The Memphis system is designed such that some small sections of the system could be checked and repaired as necessary to restore natural gas service to a few selected buildings (shelters) within 24 hours of a quake. Complete restoration of service to the community would require approximately six (6) weeks with additional sections of the community regaining service as the work progressed. Major system elements are shown in Figure ____.

Availability Analysis

The natural gas utility system for Memphis, Tennessee is not expected to be available following an occurrence of the project earthquake. This is due primarily to the likelihood of extensive system damage and to the need to shut down the system immediately following the earthquake, to prevent fire and explosions.



4. Sewage Systems

General

The City of Memphis and the immediately surrounding area are served by two contact stabilization, activated sludge wastewater treatment plants. The North Wastewater Treatment Plant has a design capacity of 135 MGD and discharges into the Mississippi River. The treatment facilities consist of an influent pumping station, grit chambers, contact-stabilization tanks, clarifiers, chlorine contact basins, and sludge treatment facilities. The T.E. Maxson Wastewater Treatment Plant (south plant) has a design capacity of 85 MGD and also discharges treated wastewater into the Mississippi River. The treatment process is basically the same as the North WWTP with an influent pumping station, grit chambers, contact-stabilization tanks, clarifiers, chlorine contact basins, and sludge treatment facilities. Both of the wastewater treatment plants are served by two separate sources of electrical power. No other auxiliary power source is available. Figure _____ shows the locations of the wastewater treatment plants.

Wastewater pumping stations are located throughout the service area. Sanitary and storm sewer systems are separate in Memphis. The sanitary sewers range in size from 8-inch to 108-inch pipe. Approximately 95 percent of the pipe in the Memphis wastewater collection system is concrete. There is also some cast iron and plastic pipe.

Availability Analysis

Table _____ shows the results of the availability analysis for the Memphis Sewer System. This system is not expected to be available. This is due to loss of electricity and structural damage to both the treatment plants, and to the collection system. Some in-line storage would be available, and, as most of the system is of gravity-flow type emergency diversion to the Mississippi River is possible.

Availability Analysis

Sewage Systems

Memphis

Number of Structures
Surveyed

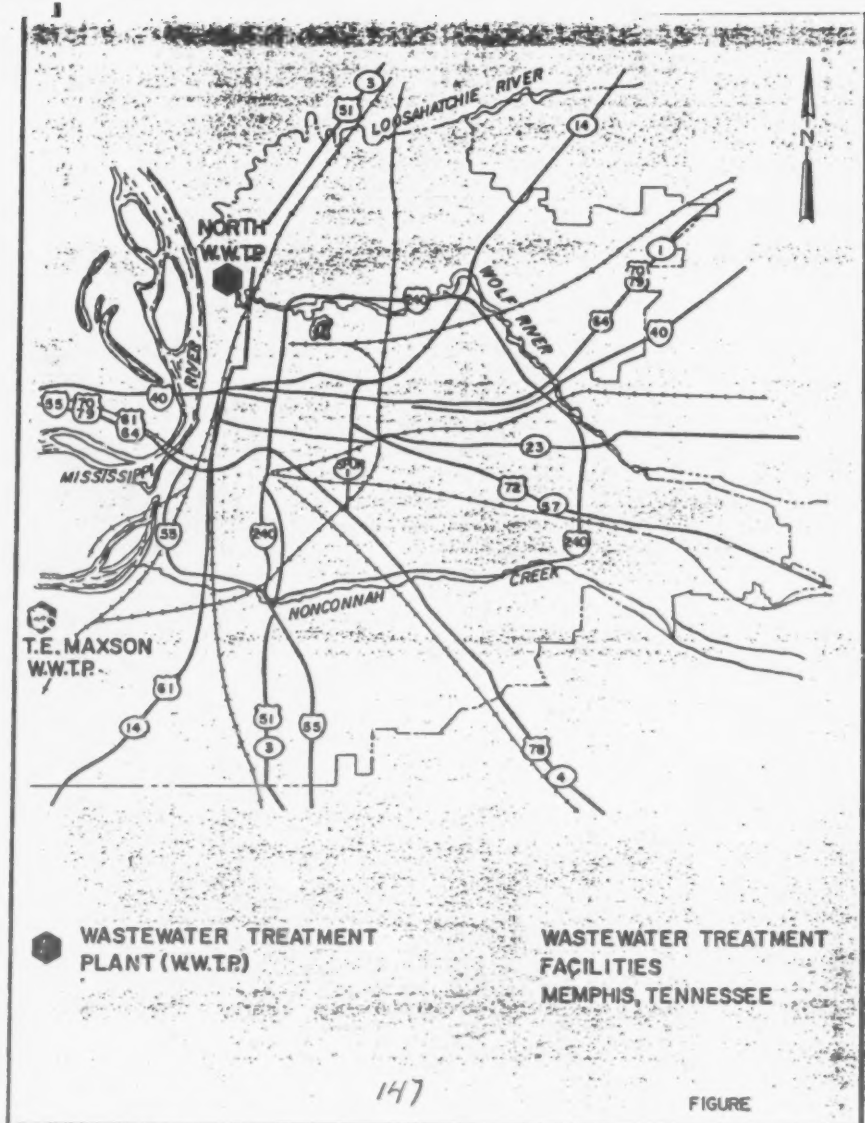
Treatment Plants 2

Structures Expected
To be Available

0/0%

System Availability
(Yes/No)

No



5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.B.4. "Conflagrations"), following the general discussion of public utilities.

III.D. Little Rock; General

The City of Little Rock is located in center of the State of Arkansas and, along with its neighboring communities, makes up the largest urbanized area in that state. With a 1980 population of approximately 158,000 persons, this city is the second most populous of the six CUSEPP cities. Little Rock is a major regional center for commerce, agriculture, education, medical services and transportation systems.

Physiographic Description (from Hopper et al, 1983, CUSEPP Report #82-3):

Little Rock is situated on the border between the Ouachita province and the Mississippi Alluvial Plain (Fenneman, 1938). Most of the city is located south of the Arkansas River, west of the Mississippi Alluvial Plain, and north of Fourche Creek in the subdued Ouachita Mountains. Within the city area these mountains have a maximum total difference in topographic relief of about 150 feet (46 m) above the Arkansas River. By comparison the Mississippi Alluvial Plain and the Arkansas River flood plain exhibit little topographic relief.

Figure _____ depicts the hypothetical ground shaking intensities expected for Little Rock. Of the six project cities, Little Rock is likely to experience the least energetic ground shaking and, consequently, the least damage, disruption and casualties. This is not to say that the CUSEPP planning earthquake would not have a significant effect upon Little Rock, for this city would definitely experience disruption and serious problems. Little Rock is likely, however, to be spared the damage expected in the other cities.

This may indicate that Little Rock and its surrounding communities could serve a major role in the coordination, staging and participation in relief efforts following a serious earthquake in this region.

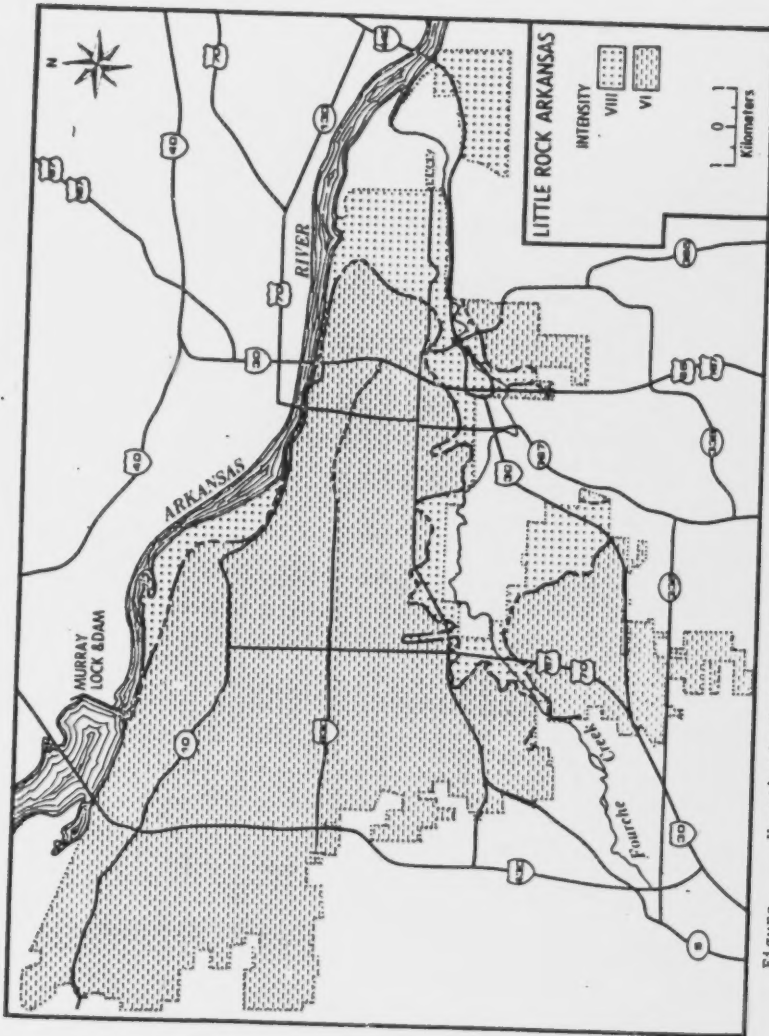


Figure 1 Hypothetical intensity map for Little Rock, Arkansas. For an earthquake near the south end of the New Madrid seismic zone, intensities projected for Little Rock are: VIII on the river alluvium, but only VI on the sandstones, shales, and limestones of the hills. For an earthquake near the north end of the New Madrid seismic zone, the intensities at Little Rock would be lower.

From: Hopper, et al, 1983 (Coseismic Report #82-3)

III.D.2. Effects on Medical Resources

Little Rock possesses a full spectrum of medical services and facilities. These entities provide medical support to the city, surrounding communities and general region. Medical services surveyed during this project were: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

The eight major hospitals consisting of 13 major structures, surveyed in Little Rock, include general admission, veteran's, children's, private and religious-affiliate facilities. These hospitals, along with those in the surrounding area, make-up a substantial concentration of health care services. Fragility analysis indicates that these facilities will not be seriously affected by the relatively moderate ground shaking anticipated to result from the CUSEPP planning earthquake. Although these facilities, can be expected to experience some earthquake-related damage, none are likely to be damaged to the extent that they will be unavailable. Hospitals will have to rely on their emergency power units doing the anticipated partial or complete loss of electric power; all hospitals have such units and they are not likely to be unavailable due to damage. At least one facility relies partially upon natural gas as fuel for its emergency power unit. As this source of energy is expected to be at least temporarily unavailable following the project quake, this factor should be taken into consideration.

The findings of the availability analysis for major hospitals in Little Rock are shown in Table ____.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Little Rock, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE _____
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
8	13	3758	13 / 100%	3758 / 100%	Yes

III.D.2.c. Blood Banks

Little Rock

Availability of blood storage facilities in _____ following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Little Rock

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	8	8/100%
Non-Hospital:	<u>2</u>	<u>10/50%</u>
Total	9	9/90%

III.D.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Little Rock following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospitals emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Little Rock

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	8	8/100%
Other	<u>-</u>	<u>-</u>
Totals	8	8/100%

III.D.2.e. Ambulance Services

The availability of ambulance service structures in Little Rock following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Little Rock

<u>Number of Structures</u>	<u>Number Expected to</u>
<u>Surveyed</u>	<u>Be Available/Percent</u>
26	25/96%

III.D.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

These findings, for the City of Little Rock, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

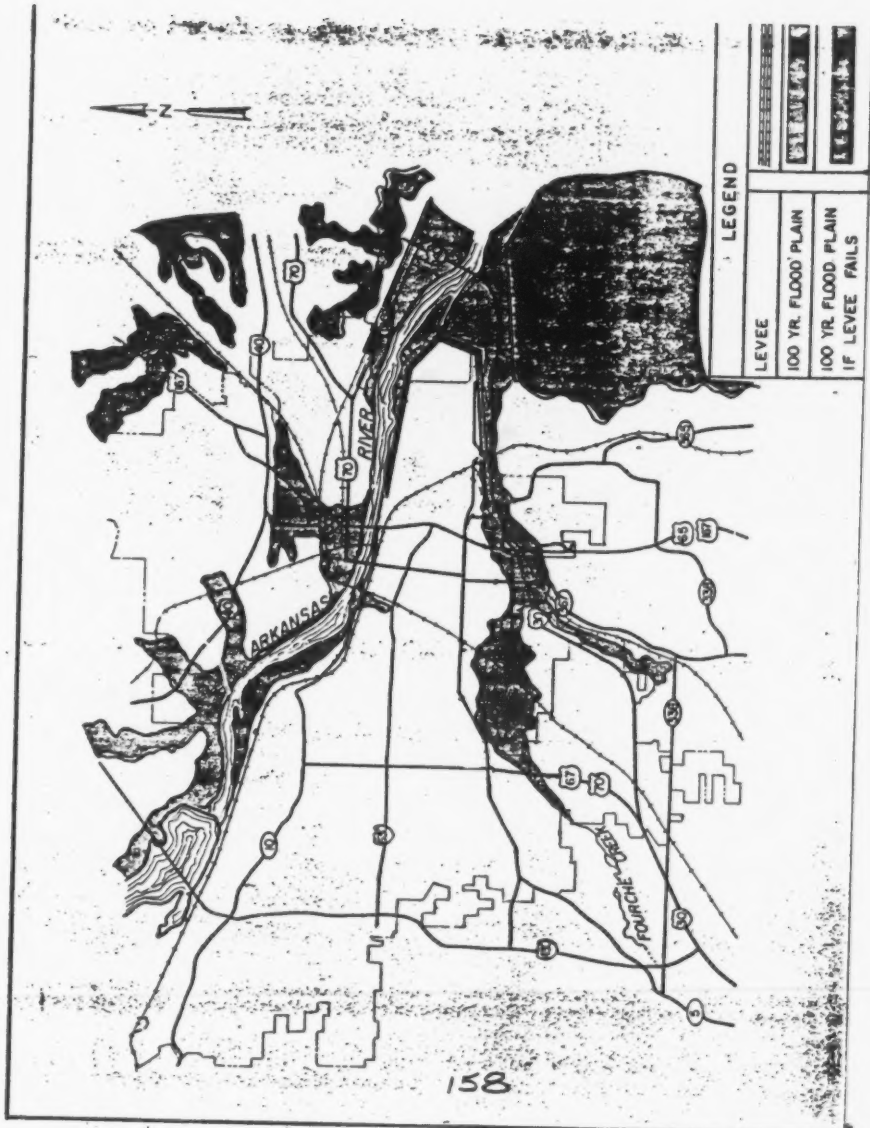
As discussed earlier, in Section III.B.2.b., casualties from the failure of dams and levees are not expected to be significant and were not estimated. The Murray lock and dam is located on the Arkansas River, just upstream and to the north of Little Rock. This dam is not expected to be damaged to the extent that it will lose its reservoir. Should this dam fail, the contribution of its reservoir to flooding in Little Rock and the surrounding region would be minor. Table ____ shows persons displaced in Little Rock due to flooding. Figure ____ depicts the inundated zones resulting from levee failure. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given in Table ____, below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE ____ Displaced Persons and Available Shelter Memphis				
<u>Flooding</u>	<u>Damage to Residences</u>		<u>Total</u>	<u>School Structures</u>
	<u>Single</u>	<u>Multi-Family</u>		<u>Available</u>
4,707	1,115	1,325	2,440	145

TABLE ____ Availability of Police Services Structures Little Rock	
<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
5	5/100%

3. Schools





III.D.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Little Rock, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table ____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE ____

Availability of Fire Service Structures

Little Rock

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
26	25/96%

2. Police Services

Table ____ shows the expected availability of police service structures in Little Rock.

Table ____ shows the expected availability of school buildings, for use as shelter and for feeding large numbers of persons.

TABLE ____
Availability of School Structures
For Shelter Purposes
Little Rock

<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
167	145/87

B. Communications

Table ____ shows the expected availability of radio, television, and telephone structures in Little Rock following the occurrence of the CUSEPP planning earthquake.

TABLE ____
Availability of Communications Structures
Little Rock

	<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
Radio	2	2/100%
Television	-	-
Total	2	2/100%

C. Transportation Systems

1. Railroads

The probabilities of survival for key rail bridges in Little Rock are shown in Table _____. The rail Maps of key rail sections are shown in Figures ____ and ____.

It is unlikely that the rail network in and around Little Rock will suffer damage which would significantly impair its use. Most links have survival probabilities equal to 100% and only two have sections with a probability as low as 94%.

TABLE III-3-3
PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN LITTLE ROCK
WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Struct.			Independent	Total Dependent
1	CRI&P-B1	0	0	2	VIII	1.00	1.00
2	CRI&P-B2	0	0	2	VIII	1.00	1.00
3	CRI&P-ML	2	0	1	VI	1.00	1.00
4	CRI&P-ML	1	0	2	VI/VIII	.99	.99
5	CRI&P-ML	4	0	5	VI/VIII	.97	.99
7	CRI&P-ML	1	0	4	VI	1.00	1.00
8	CRI&P-WB	2	0	7	VI	1.00	1.00
9	CRI&P-WB	0	0	4	VI/VIII	1.00	1.00
10	CRI&P-WB	3	0	0	VI	1.00	1.00
11	MOPAC-B1	2	0	2	VIII	.98	.99
12	MOPAC-B2	2	0	0	VIII	.99	.99
13	MOPAC-B3	0	1	4	VIII	1.00	1.00
14	MOPAC-B4	0	0	2	VI	1.00	1.00
15	MOPAC-CN	4	0	6	VI	1.00	1.00
16	MOPAC-LA	0	0	1	VI	1.00	1.00

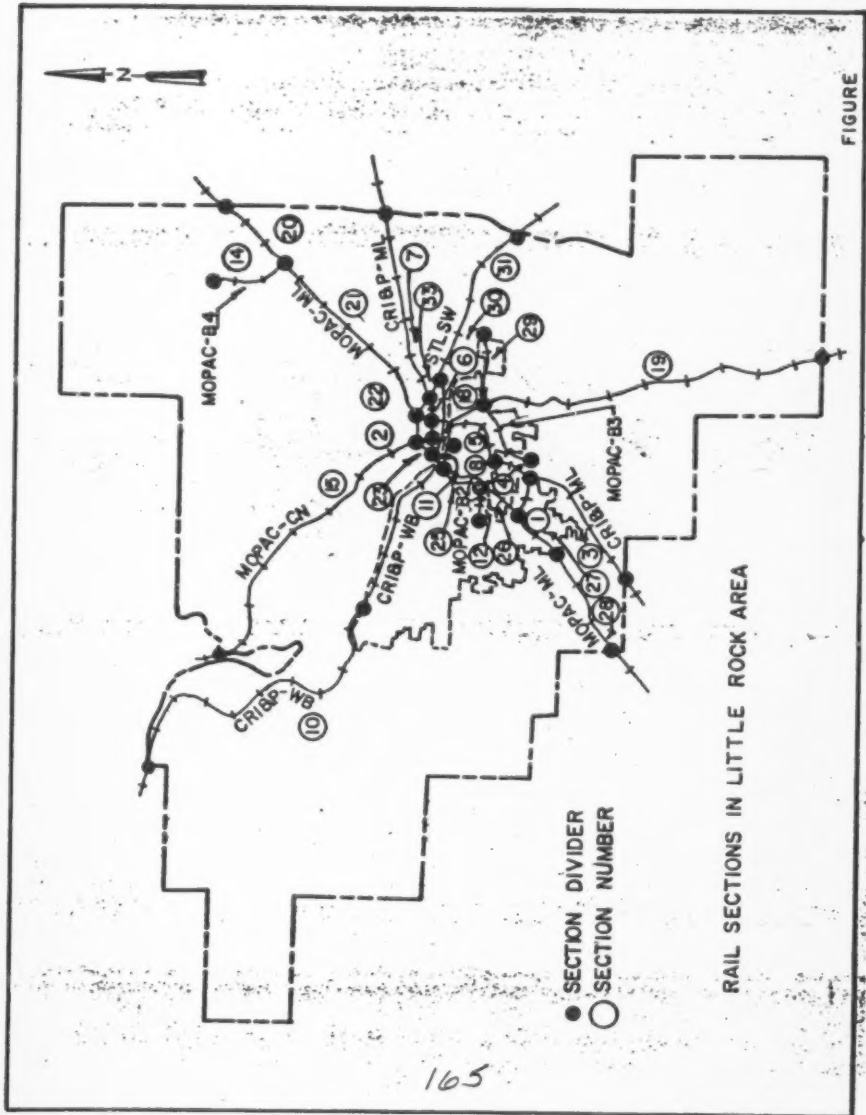
TABLE III-3-3

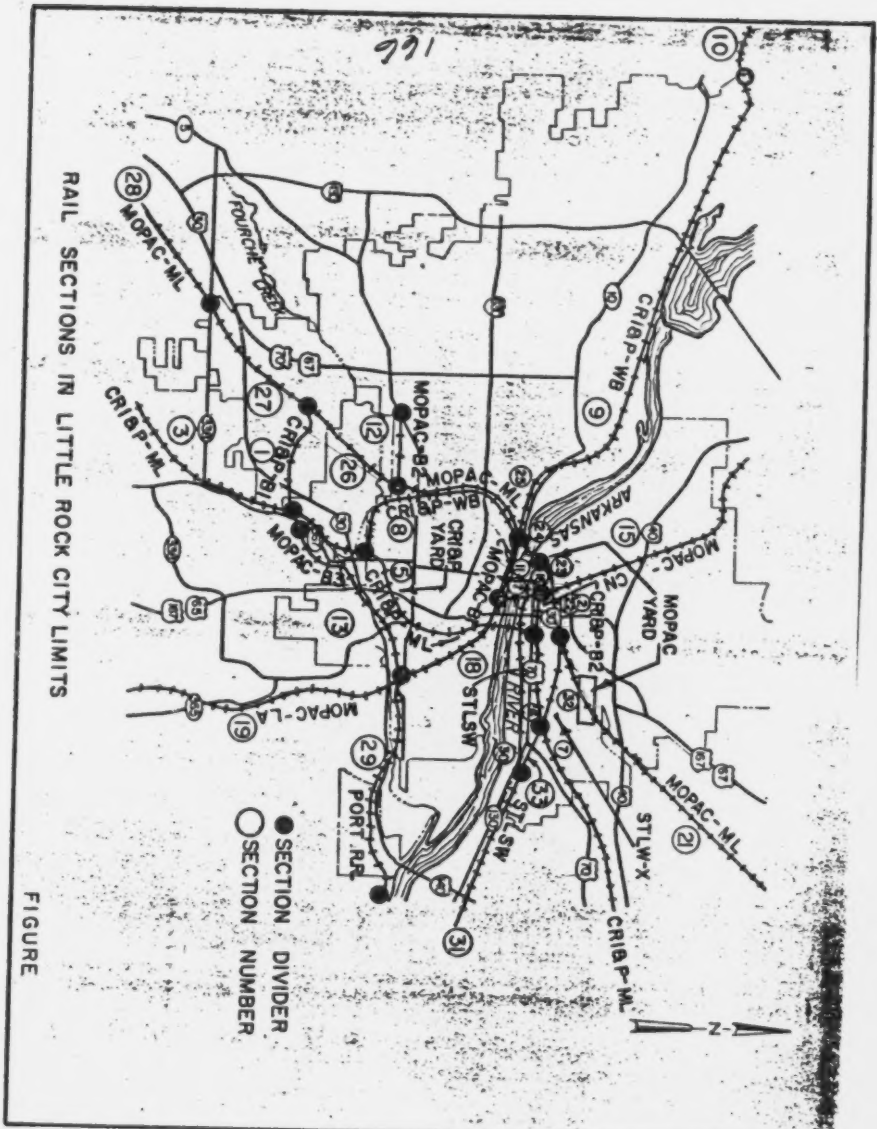
PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN LITTLE ROCK (Continued)

Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Structures			Total Independent	Total Dependent
17	MOPAC-LA	2	2	0	VIII	.94	.94
18	MOPAC-LA	0	1	1	VI/VIII	1.00	1.00
19	MOPAC-LA	7	0	2	VI/VIII	1.00	1.00
20	MOPAC-ML	0	3	0	VI	1.00	1.00
21	MOPAC-ML	0	3	2	VI	1.00	1.00
22	MOPAC-ML	0	0	3	VI	1.00	1.00
23	MOPAC-ML	0	1	1	VI/VIII	1.00	1.00
24	MOPAC-ML	1	0	2	VIII	1.00	1.00
25	MOPAC-ML	0	2	8	VI	.94	.94
26	MOPAC-ML	0	2	0	VIII	1.00	1.00
27	MOPAC-ML	0	1	2	VI	1.00	1.00
28	MOPAC-ML	0	2	0	VI	1.00	1.00
29	PORT RR	1	0	2	VIII	.99	.99
30	STLSW	0	0	5	VIII	1.00	1.00
31	STLSW	0	0	2	VIII	1.00	1.00

Note:

- 1 Probability that the line segment would survive
- 2 Section with no structures:
6 CRISP-ML
- 3 32, 33 STLSW-X
- 4 One 3-parallel structures and two 2-parallel structures





2. Highways

Highway survival probabilities for Little Rock's sections are shown in Table _____. The highway systems are shown in Figures ____ and ____.

No highway sections are expected to fail in Little Rock. The lowest probability of survival is 97% while most of the sections have a 100% estimate of survival.

Because Little Rock's transportation network is expected to be substantially undamaged, it may be a good candidate as a regional response center to coordinate post-quake activities.

TABLE III-3-9

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
LITTLE ROCK WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Route	Number of Structures Supporting Route		Number of Structures Over Route	Earthquake Intensity	P (Survival)	
		Single Structures	Pairs of Parallel Struc.			Total Independent	Total Dependent
1	I30	0	2	2	VI	1.00	1.00
2	I30	1	0	2	VI	1.00	1.00
3	I30	0	4	2	VI/VIII	1.00	1.00
4	I30	0	2	3	VIII	1.00	1.00
5	I30	0	2	1	VI/VIII	1.00	1.00
6	I30	1	1	4	VI	1.00	1.00
7	I30	3	0	0	VIII	.97	1.00
8	I30	8	2	2	VI	1.00	.99
10	I40	0	3	3	VI	1.00	1.00
11	I40	1	2	6	VI	1.00	1.00
12	I40	1	1	3	VI	1.00	1.00
13	I40	1	0	3	VI	1.00	1.00
14	I40	0	2	4	VI	1.00	1.00
15	I40	1	0	2	VI	1.00	1.00
16	I430	2	2	1	VI/VIII	1.00	1.00
17	I430	2	2	4	VI	1.00	1.00
18	I430	2	3	5	VI	1.00	1.00
19	I430	1	2	2	VI	1.00	1.00
20	I440	3	1	1	VIII	1.00	1.00
21	I440	0	3	1	VIII	.98	.98
22	I440	1	1	1	VIII	1.00	1.00
23	I440	0	3	0	VIII	.99	.99
24	I440	0	2	1	VI	1.00	1.00
25	I630	1	2	0	VI	1.00	1.00
26	I630	2	2	5	VI	1.00	1.00
27	SR5	4	0	5	VI	1.00	1.00
28	SR5	2	0	0	VI	1.00	1.00
29	SR5	1	0	0	VI	1.00	1.00
30	SR10	4	0	0	VIII	.99	.99
31	SR10	14	0	0	VI	1.00	1.00
32	SR10	1	0	0	VI	1.00	1.00
34	SR10	1	2	1	VI	1.00	1.00
35	SR10	4	0	2	VI	1.00	1.00

TABLE III-3-9

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
LITTLE ROCK (Continued)

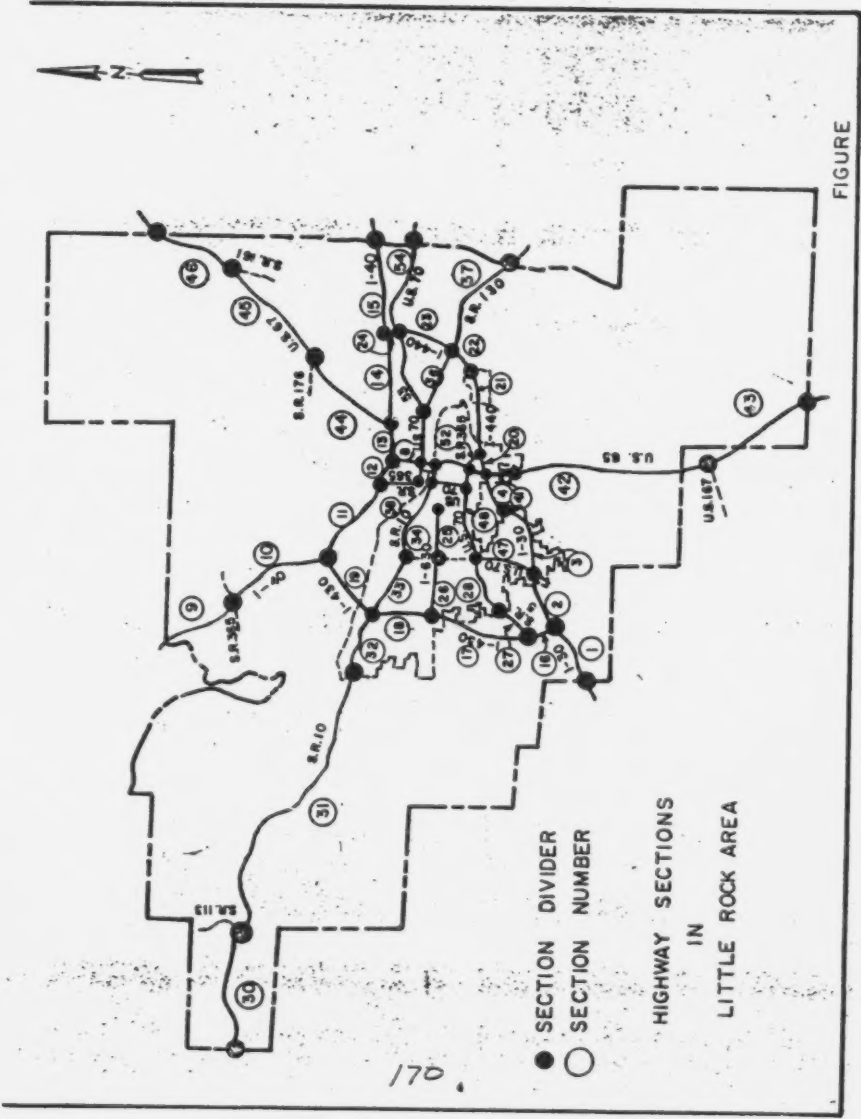
Section ²	Number of Structures Supporting Route		Number of Structures Earthquake Over Route Intensity	P (Survival)	
	Route	Single Structures		Total Independent	Total Dependent
36	SR130	0	0	1.00	1.00
37	SR130	1	0	1.00	1.00
38	SR365	0	0	1.00	1.00
39	SR365	0	0	1.00	1.00
40	SR365	2	0	1.00	1.00
41	US65	4	0	.98	.99
42	US65	4	1	.97	.99
43	US65	0	2	1.00	1.00
44	US67	3	3	1.00	1.00
45	US67	2	3	1.00	1.00
46	US67	1	2	1.00	1.00
47	US70	0	2	1.00	1.00
48	US70	5	2	1.00	1.00
50	US70	1	0	1.00	1.00
51	US70	0	0	1.00	1.00
52	US70	0	0	.99	.99
53	US70	1	0	1.00	1.00
				1.00	1.00

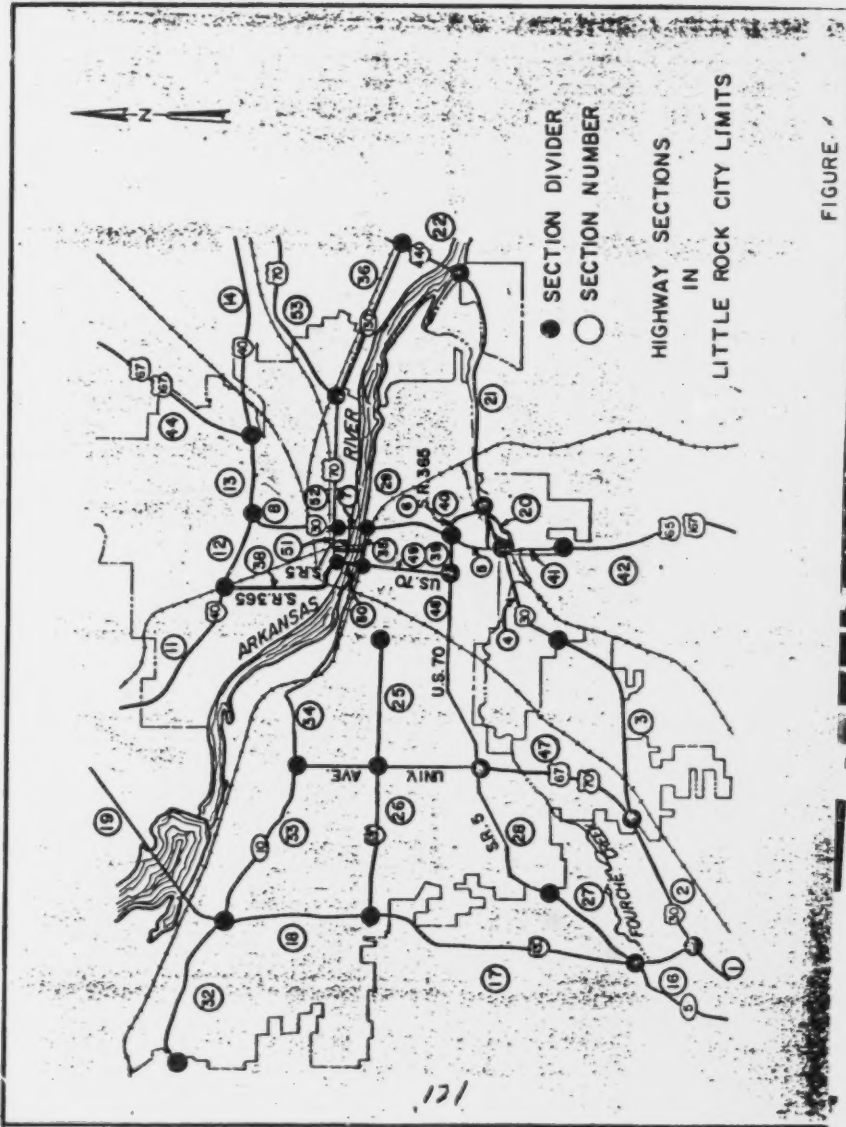
Notes:

1 Probability that the route segment would survive

2 Sections with no structures:

9 I40
33 SR10
49, 54 US70





3. Docks (River Ports)

Due to the generally unfavorable soil conditions which are typical for the river bank locations of port and dock facilities, it is expected that these facilities will not be available for use in Little Rock following an occurrence of the CUSEPP planning earthquake. Figure _____ shows the location of river port and dock facilities for Little Rock.

4. Airports

As discussed in the general section on airports, (Section III.B.3.c.4.) airport runways will ^{generally} be at least partially available for use in Little Rock following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for others in the area of similar structural type. Figure _____ shows the location of major airport facilities for Little Rock.

FIGURE _____

Location of River Ports
and
Airports

- this material to be supplied for Final Draft -

d. Public Utilities

1. Electric Utilities

General

Arkansas Power & Light (AP&L) is major power supplier to the city of Little Rock/North Little Rock, population 200,000. AP&L, an investor owned utility, supplies power to most of the towns in Arkansas and has several major 115 kV ties throughout the city. One generating plant, Lynch, owned by AP&L, is located in Little Rock, with a generating capacity of 265 MW. Total generating capacity is 4,000 MW. AP&L has 3,700 employees, several branch/district offices and radio equipped vehicles located throughout the state. Figure _____ shows major elements of the Little Rock electric utility system.

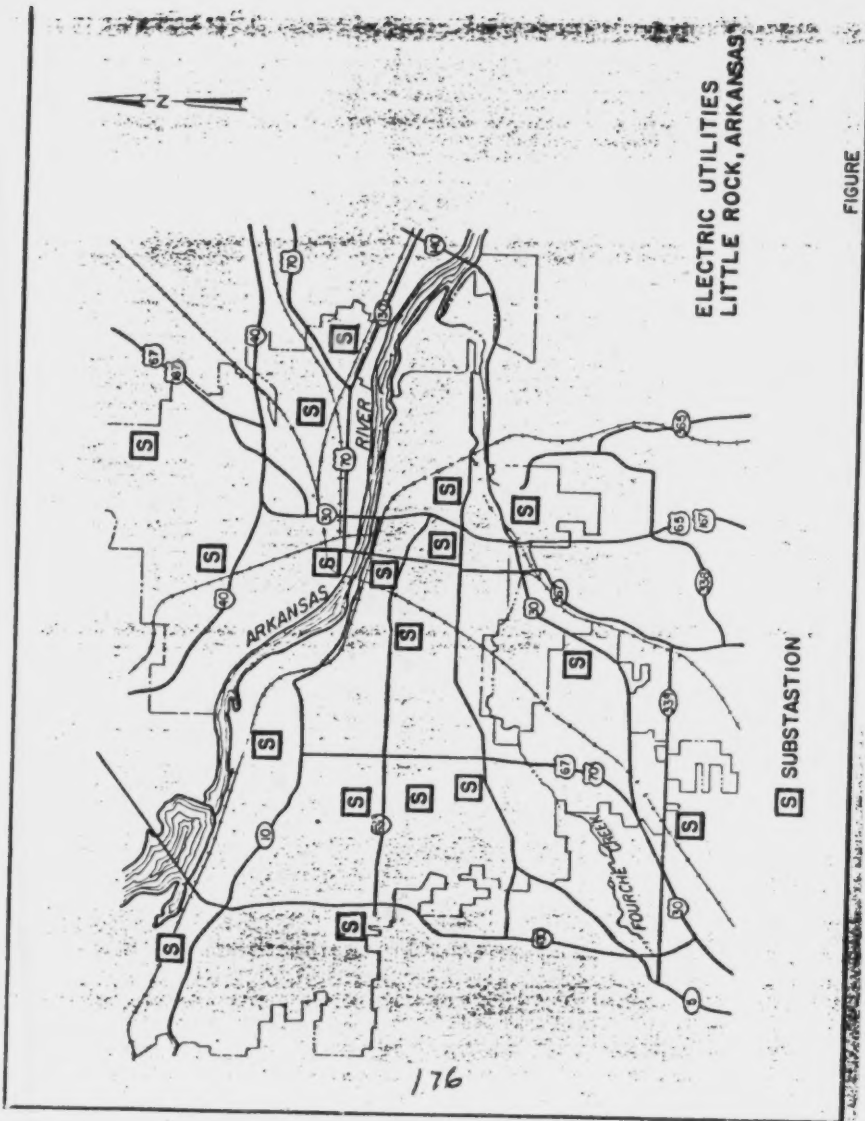
Availability Analysis

Table _____ presents the results of the availability analysis for Little Rock's electric utility system. This system is expected to suffer the least damage of any project City. The system is likely to be unavailable immediately following an occurrence of the project quake, but will probably be able to be placed back in service relatively quickly. Spare and replacement components may be available from other near-by utilities to the south and west.

TABLE _____
Availability of Electric Utilities

Little Rock

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 18	12/67%	—
Power Plants 1	1/100%	—
TOTAL 19	13/68%	No (partial)



2. Water Utility

General

The City of Little Rock and surrounding areas are served by two water treatment plants, Ozark Point and Pleasant Valley. The source of water for the system is surface water, supplied by Lake Winona and Big Maumelle Lake. The Ozark Point water treatment plant has a capacity of 46 MGD. Lake Winona supplies a maximum of 23 MGD via a 39-inch gravity transmission pipe. Supplemental water is pumped from Big Maumelle Lake. The treatment operations at Ozark Point consist of pre-chlorination, coagulation, flocculation, fluoridation and post-chlorination. The Pleasant Valley water treatment plant presently has a 50 MGD capacity. Expansion of the plant to 100 MGD is underway and will be completed in 1984. The main source of water for Pleasant Valley is Big Maumelle Lake pumped in 48 and 72-inch pipe. Due to the algae in the water activated carbon is used at Pleasant Valley. All other treatment operations are as at Ozark Point. The water treatment plant locations are indicated in Figure_____.

The distribution system is composed primarily of cast iron pipe ranging in size from 6 inches to 36 inches. Booster pumping stations are dispersed throughout the city, particularly in the outlying areas. The pumping stations are often located at a storage tank. The Waterworks Department operates a total of ten (10) booster pumping stations which are shown in Figure_____. The stations, number of pumps and total capacity are shown in Table_____.

The system has 35.265 million gallons of storage capacity in a combination of underground, ground and elevated tanks. Three 5.0 MG clearwells are used at the Ozark Point plant and one 5.0 MG clearwell is located at the Pleasant Valley plant. The ground and elevated storage tanks are located throughout the service area as indicated on the map, Figure _____. Most of the ground storage tanks have booster pumping stations. Descriptions of the storage tanks and their capacities are listed in Table _____.

Availability Analysis

Table _____ presents the findings of the availability analysis for Little Rock's water system. The "conditional" affirmative finding for the system's availability is based on the city's electrical system not sustaining major damage, and being restorable relatively promptly. This, combined with the survival of most elevated storage tanks, is likely to allow this system to have at least limited availability following the project earthquake.

Availability Analysis

Water Utility

Little Rock

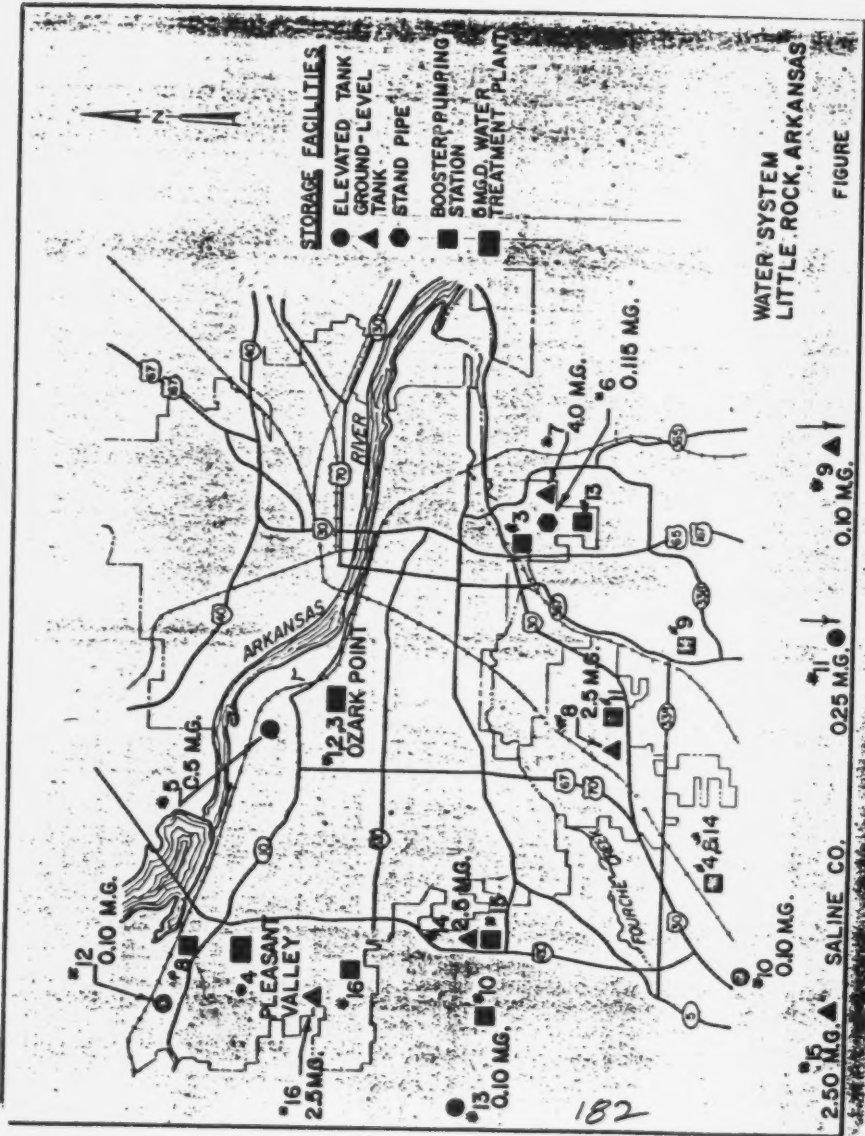
<u>Total Number of Structures Surveyed</u>		<u>Structures Expected To be Available/Percent</u>	<u>System Availability (Yes/No)</u>
Treatment Plants:	2	2/100%	—
Storage Tanks elevated:	6	3/50%	—
Non-elevated:	10	10/100%	—
Pump Stations:	<u>10</u>	<u>10/100%</u>	—
TOTAL	28	25	<u>Yes (conditional)</u>

TABLE _____
BOOSTER PUMPING STATIONS
LITTLE ROCK, ARKANSAS

<u>STATION NO.</u>	<u>NO. OF PUMPS</u>	<u>TOTAL CAPACITY, gpm</u>
3	2	1,470
4	3	900
8	2	2,460
9	3	2,133
10	2	580
11	2	5,600
13	1	2,800
14	2	5,000
15	3	4,200
16	4	6,900

TABLE _____
STORAGE FACILITIES
LITTLE ROCK, ARKANSAS

<u>NUMBER</u>	<u>CAPACITY, MG</u>	<u>DESCRIPTION</u>
1	5.0	Ground, Concrete, Clearwell #2, Ozark Pt. WTP
2	5.0	Ground, Concrete, Clearwell #3, Ozark Pt. WTP
3	5.0	Ground, Steel, Clearwell #4, Ozark Pt. WTP
4	5.0	Ground, Concrete, Clearwell, Pleasant Valley WTP
5	0.50	Elevated, Steel
6	0.115	Standpipe, Steel
7	4.0	Ground, Steel
8	2.50	Ground Steel
9	0.10	Elevated, Steel
10	0.10	Elevated, Steel
11	0.25	Elevated, Steel
12	0.10	Elevated, Steel
13	0.10	Elevated, Steel
14	2.50	Ground, Concrete
15	2.50	Ground, Concrete
16	2.50	Ground, Concrete
TOTAL	35.265	



3. Natural Gas Utility

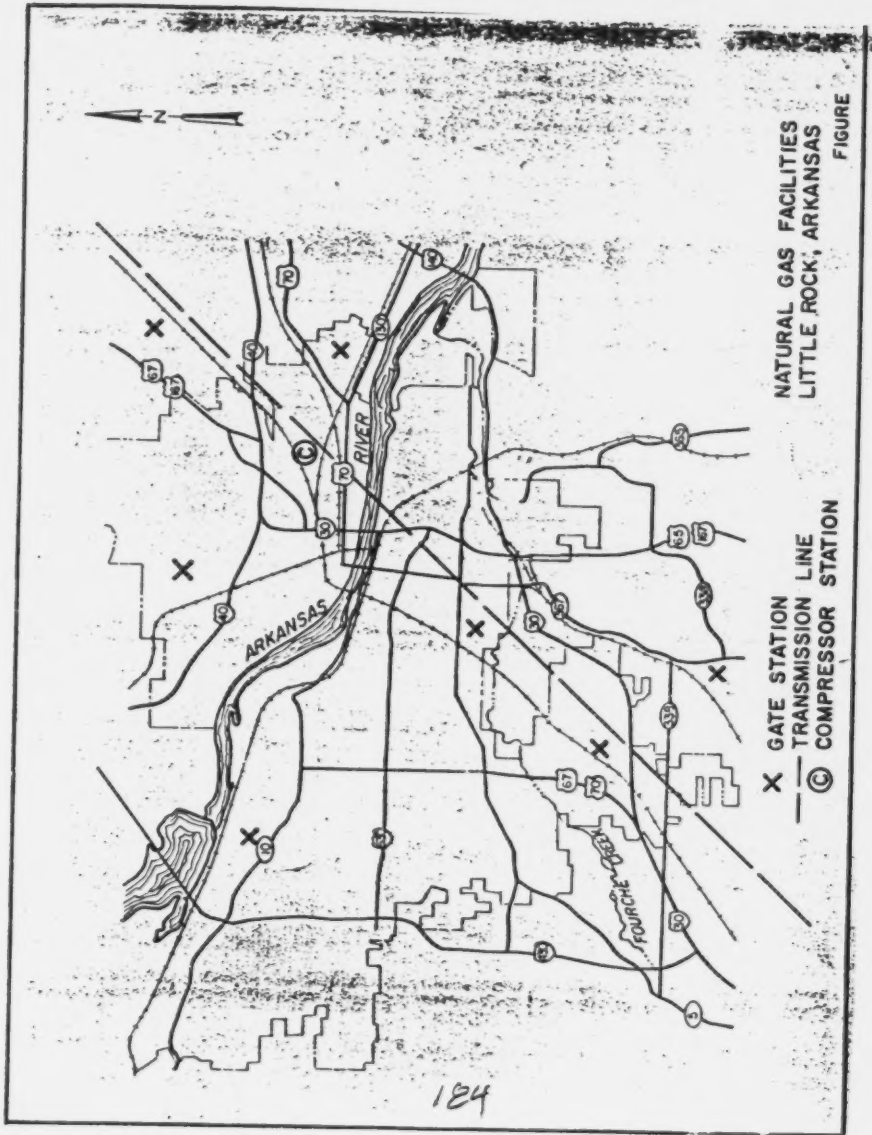
The natural gas system of Little Rock, Arkansas is operated by Arkla, Inc. The system has 3 purchase points and approximately 1000 regulator stations. Little Rock purchases its gas from Arkla who buys gas from several pipelines at the well head or pipeline connections. There are no storage facilities for propane-air or LNG. Approximately, 950 miles of piping make up the system, most of which is steel and the remaining being plastic.

The steel and plastic piping making up the natural gas system serving Little Rock would fair well in a major quake. A few isolated line ruptures might occur. However, damage to service piping and meter sets would require that the system be shut-off immediately following a major quake.

Some areas of the system could be restored to service within 24 hours to provide heat to certain shelter areas. The full system could be restored in one to two weeks. Figure _____ shows major system elements.

Availability Analysis

Little Rock's natural gas system is expected to be unavailable following the project earthquake. Even though damage is likely to be minor, the system would be immediately shut down to prevent fire and explosion.



4. Sewage System

General

The Little Rock Sewer Department operates two wastewater treatment plants which discharge into the Arkansas River. The Adams Field WWTP is an activated sludge facility with a design capacity of 27 MGD. The operations at the WWTP include influent pumping, clarification, aeration, sludge thickening and filtration. There is only one electrical feed into the plant and no auxiliary power facilities are available. The Fourche WWTP is a 15 MGD rotating biological contractor (RBC) plant. Construction of this WWTP was recently completed and it has been on-line only a short time. Wastewater is pumped to the plant by a pumping station approximately two miles away. The RBC treatment system will be operated with gas produced in the anaerobic digester. When in full operation, the plant will be self-sufficient from an energy standpoint. The location of each wastewater treatment plant is indicated in Figure_____.

The Little Rock wastewater collection system is served by seventeen (17) lift stations located throughout the service area. The storm and sanitary wastewater systems are separate. The sanitary sewers range in size from 10 inches to 72 inches in diameter. Pipe installed in the last ten years is ABS truss pipe. Older pipe is primarily clay and concrete.

Availability Analysis

Table _____ gives the results of the available analysis for this system. Based on fragility considerations and system specific factors and due to the low levels of ground shakers anticipated, this system is expected to be available following the project earthquake.

Availability Analysis

Sewage Systems

Little Rock

Number of Structures
Surveyed

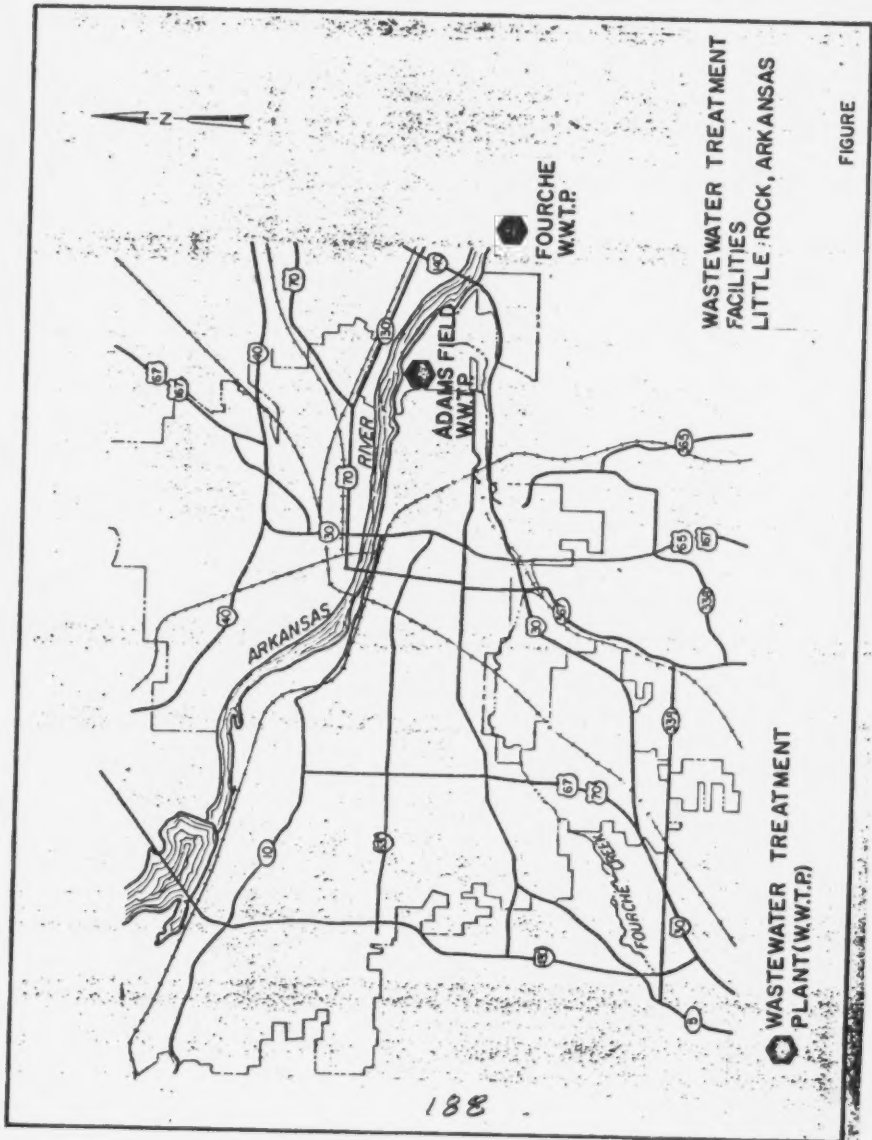
Treatment Plants 2

Structures Expected
To be Available

2/100%

System Availability
(Yes/No)

Yes



5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.B.4. "Conflagrations"), following the general discussion of public utilities.

II.E. Evansville; General

The City of Evansville is located in extreme southwest Indiana, on the north bank of the Ohio River. This city is the third most populous of the CUSEPP cities, with a 1980 population of approximately 130,000 persons, and is a major regional center for commerce, medical services, industry and education.

Physiographic Description (from Hopper, et al; CUSEPP Report #82-3):

Evansville is situated along the Ohio River in the Interior Low Plateaus province (Fenneman, 1938). Topographic relief within the city proper is low; some of the banks along the Ohio River are steep.

Figure _____ shows the hypothetical ground shaking intensities expected in Evansville were the CUSEPP planning earthquake to occur. These levels of ground motion will cause significant damage and disruption in Evansville, as reflected in the findings presented in this section.

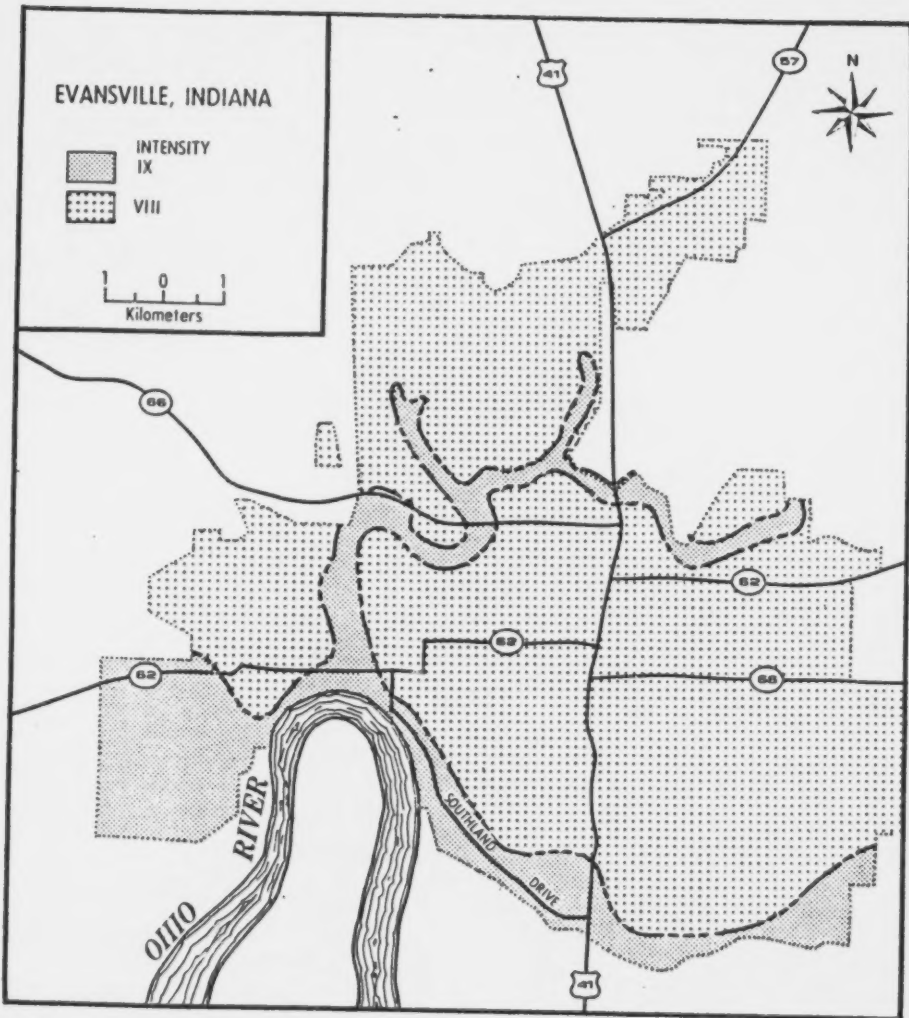


Figure _____ Hypothetical intensity map for Evansville, Indiana. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Evansville are: IX along the Ohio River flood plain and its tributary and VIII for the lacustrine sediments of the rest of the city. For an earthquake near the south end of the New Madrid seismic zone, the intensity at Evansville would be lower.

from: Hopper, et al, 1983 (CUSEPP Report # 82-3)

III.E.2. Effects on Medical Resources

Evansville possesses a full spectrum of medical services and facilities. These entities provide medical support to the city, surrounding communities and general region. Medical services surveyed during this project were: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

The city of Evansville is served by four major hospitals. The 20 major structures comprising these facilities were analyzed for their availability following the project earthquake. Evansville hospitals will sustain relatively little severe damage with 90% of buildings and hospital beds expected to be available. All facilities are equipped with emergency electrical power units, which are likely to be available. Table _____ shows the finding of the availability analysis for major hospital service in Evansville.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Evansville, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
4	20	2242	18 / 90%	2027 / 90%	Yes

III.E.2.c. Blood Banks

Availability of blood storage facilities in *Evansville* following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Evansville

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	4	4/100%
Non-Hospital:	<u>3</u>	<u>2/67%</u>
Total	7	6/86%

III.E.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Evansville following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospitals emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Evansville

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	4	4/100%
Other	<u>2</u>	<u>1/50%</u>
Totals	6	5/83%

III.E.2.e. Ambulance Services

The availability of ambulance service structures in Evansville following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Evansville

<u>Number of Structures</u>	<u>Number Expected to</u>
<u>Surveyed</u>	<u>Be Available/Percent</u>
3	3/100%

III.E.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

These findings, for the City of Evansville, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

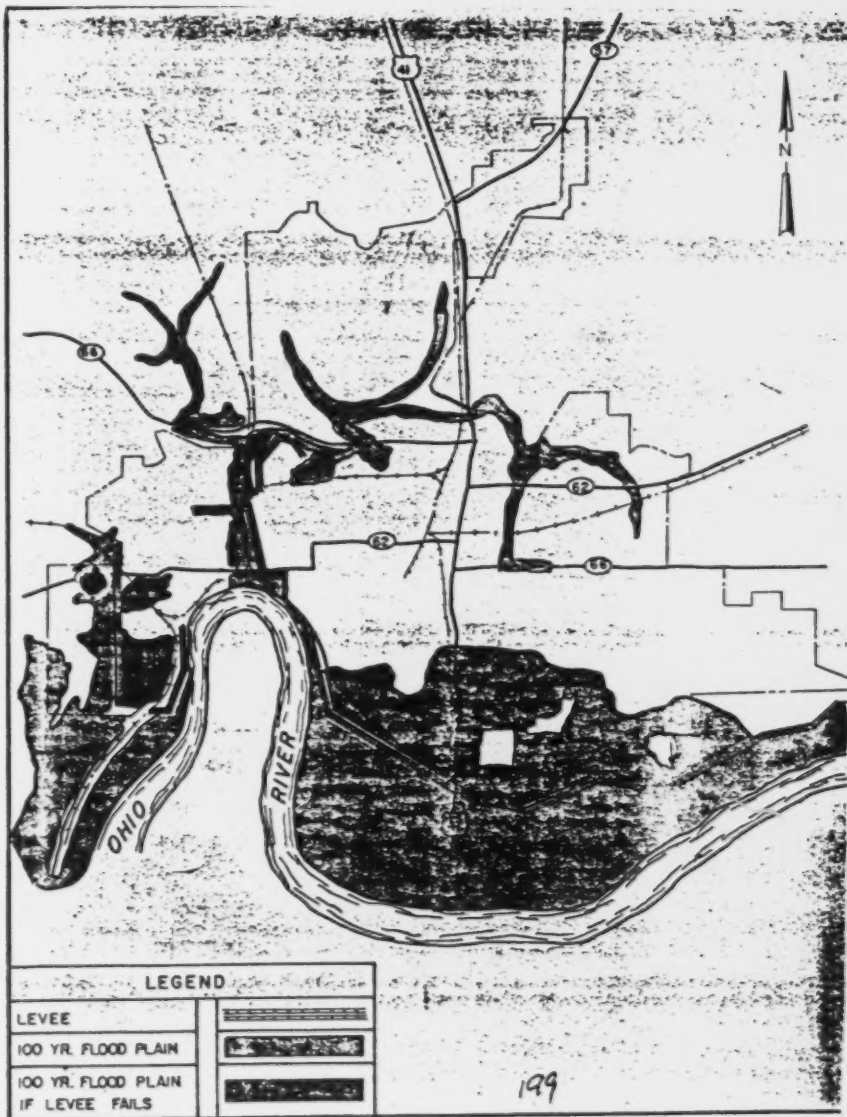
As discussed earlier, in Section III.B.2.b., casualties from the failure of dams and levees are not expected to be significant and were not estimated. Table _____ depicts the numbers of persons displaced by flooding due to levee failure. Figure _____ shows areas of Evansville expected to be flooded. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given in Table _____ below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE Displaced Persons and Available Shelter Memphis				
	Damage to Residences			School Structures
Flooding	Single	Multi-Family	Total	Available
17,497	7,583	3,513	11,095	29

TABLE Availability of Police Services Structures Evansville	
Total Structures Surveyed	Structures Expected To Be Available/Percent
1	1/100%

3. Schools

Table _____ shows the expected availability of school buildings, for use as shelter and for feeding large number of persons.



36-489 0341

III.E.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Evansville, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table _____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE _____

Availability of Fire Service Structures
Evansville

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
11	10/91%

2. Police Services

Table _____ shows the expected availability of police service structures in Evansville.

TABLE
Availability of School Structures
For Shelter Purposes
Evansville

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
81	29/36%

b. Communications

Table _____ shows the expected availability of radio, television, and telephone structures in Evansville following the occurrence of the CUSEPP planning earthquake.

TABLE
Availability of Communications Structures
Evansville

	<u>Total Structures</u>	<u>Structures Expected</u>
	<u>Surveyed</u>	<u>To Be Available/Percent</u>
Radio	5	4/80%
Television	-	-
Telephone	5	4/80%
Total	10	8/80%

C. Transportation Systems

1. Railroads

Survival probabilities for key rail bridges are found in Tables ____ and _____. Figures ____ and ____ show key rail system elements for Evansville and its vicinity.

Only three rail sections are candidates for failure: Conrail where it crosses Pigeon Creek, L & N along the western shore of the Ohio River, and L & N (CEI) crossing Pigeon Creek from the North. If all these routes were to fail (an extremely unlikely event), there is sufficient redundancy in the rail network to maintain adequate accessibility by the use of alternative routes. Given this redundancy and the relatively high probability of survival of even the weakest links, it is estimated that rail service to Evansville would not experience serious disruption as a result of the project earthquake.

TABLE III-3-2

PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN EVANSVILLE
WOULD SURVIVE NEW MADRID EARTHQUAKE

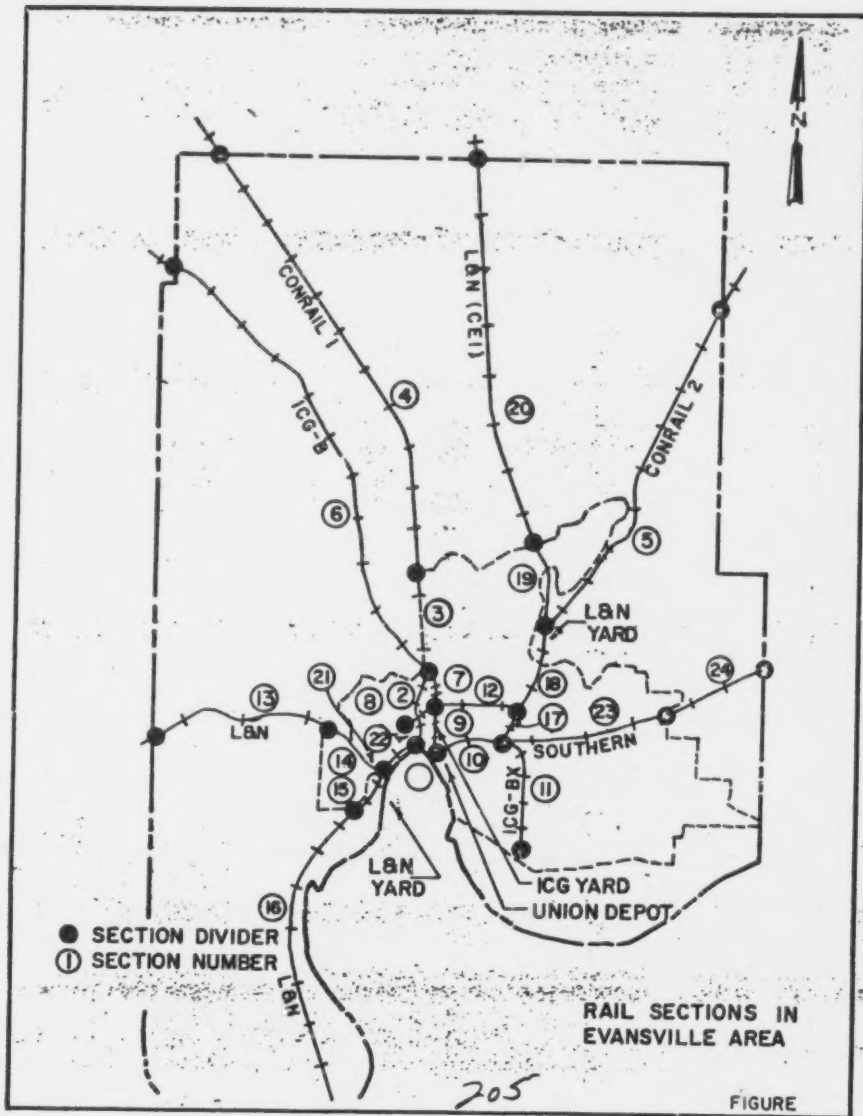
Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Structures			Total Independent	Total Dependent
1	CONRAIL1	1	0	0	IX	.94	.94
2	CONRAIL1	1	0	0	IX	.89	.94
3	CONRAIL1	1	0	4	VIII	.99	.99
4	CONRAIL1	1	0	0	VIII	.99	.99
5	CONRAIL2	2	0	4	VIII	.99	.99
6	ICG-B	9	0	0	VIII	.98	.99
7	ICG-B	1	0	1	IX	.92	.99
8	ICG-B	1	0	1	IX	.95	.96
13	L&N	1	0	0	IX	.94	.94
14	L&N	0	0	0	VIII	.99	.99
15	L&N	0	0	1	IX	.99	.99
16	L&N	2	0	1	IX	.98	.99
17	L&N (CEI)	1	0	0	IX	.88	.94
18	L&N (CEI)	2	0	0	IX	.96	.96
19	L&N (CEI)	1	0	0	IX	.88	.94
20	L&N (CEI)	2	0	0	VIII	.99	.99
22	L&N (SPUR)	0	0	2	VIII	.98	.99
23	SOUTHERN	1	0	2	IX	.98	.99
				0	VIII	1.00	1.00

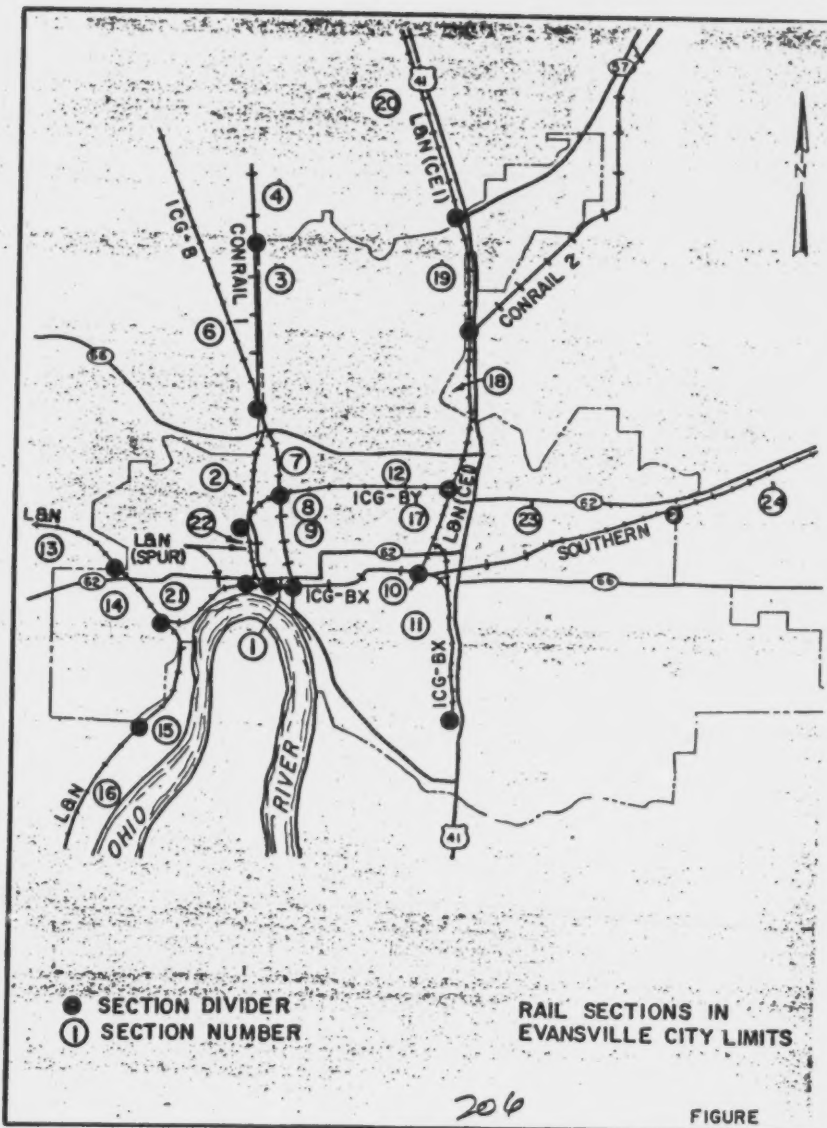
Notes:

1 Probability that the line segment survives.

2 Sections with no structures:

9, 10, 11 ICG-BX
12 ICG-BY
21 L&N (SPUR)
24 SOUTHERN





2. Highways

Table _____ contains the survival probabilities for Evansville's highways. Figures _____ and _____ show the highway network.

Four sections have survival probabilities of less than the 90% criterion, only one being below 80%. Highway C056 from the east, which consists of sections 2 and 3, has a combined survival probability of less than 60% and may be considered a likely failure. Section 9 on State Route 62 passes through the same region and has a survival probability of 83%. If both routes were closed, accessibility from the south-west would require a diversion; however, the probability of both failing is less than 5% (i.e. very unlikely). US 41 from the north (section 27) has a survival probability of 89% and since good alternative routes exist, accessibility from the north should continue to be available.

In summary, adequate highway accessibility to, and within, Evansville is very likely following the project earthquake.

TABLE III-3-8

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN EVANSVILLE
WOULD SURVIVE NEW MADRID EARTHQUAKE

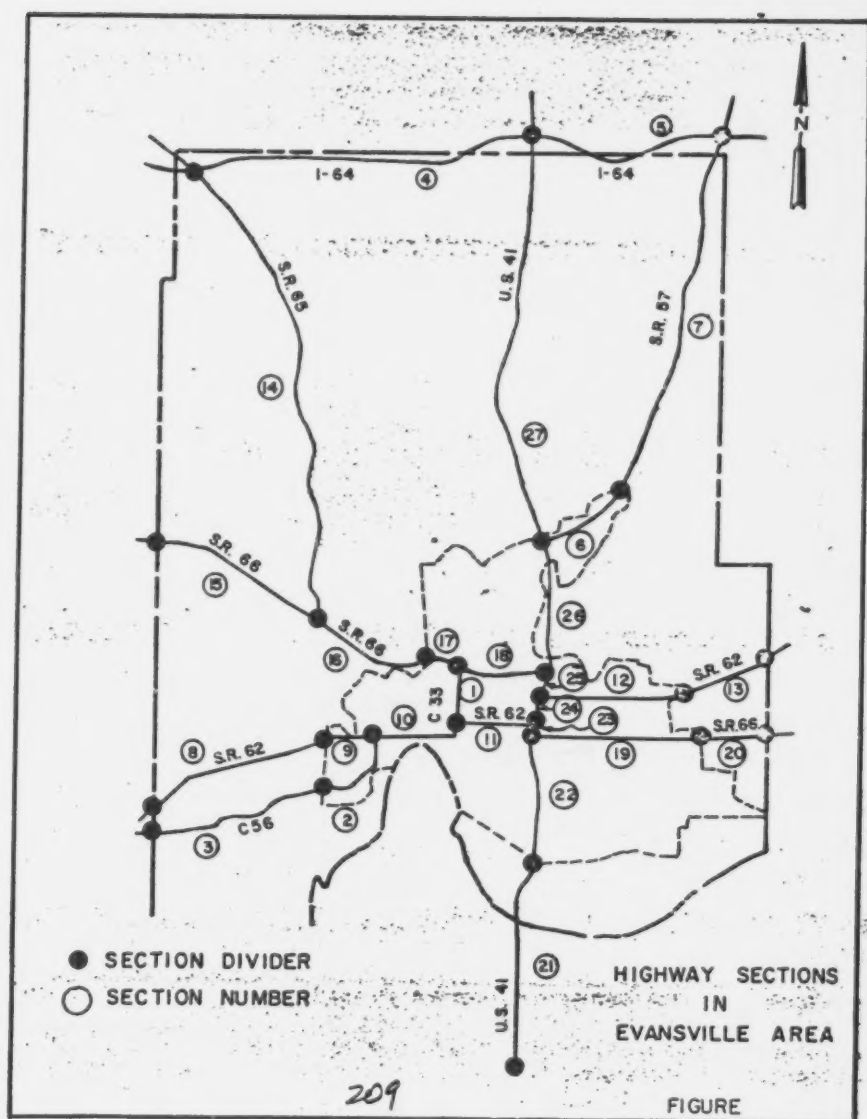
Section ²	Route	Number of Structures Supporting Route		Number of Structures Over Route	Earthquake Intensity	P (Survival)	
		Single Structures	Parallel Pairs of Structures			Independent	Total Dependent
1	C033	1	0	0	IX	.94	.94
2	C056	3	0	0	IX	.65	.74
3	C056	2	0	0	IX	.88	.94
4	I64	0	3	3	VIII	1.00	1.00
5	I64	0	2	2	VIII	1.00	1.00
7	SR57	3	0	2	VIII	.97	.99
9	SR62	3	0	0	IX	.83	.94
10	SR62	1	0	2	VIII/IX	.96	.98
14	SR65	2	0	0	VIII	.97	.97
15	SR66	0	1	0	VIII	1.00	1.00
16	SR66	4	0	0	VIII	.94	.97
18	SR66	2	0	0	VIII/IX	.93	.96
19	SR66	0	0	2	VIII	1.00	1.00
21	US41	0	3	0	IX	.97	.97
23	US41	0	1	0	VIII	1.00	1.00
26	US41	1	1	0	VIII/IX	1.00	1.00
27	US41	4	2	2	VIII	.89	.94

Notes:

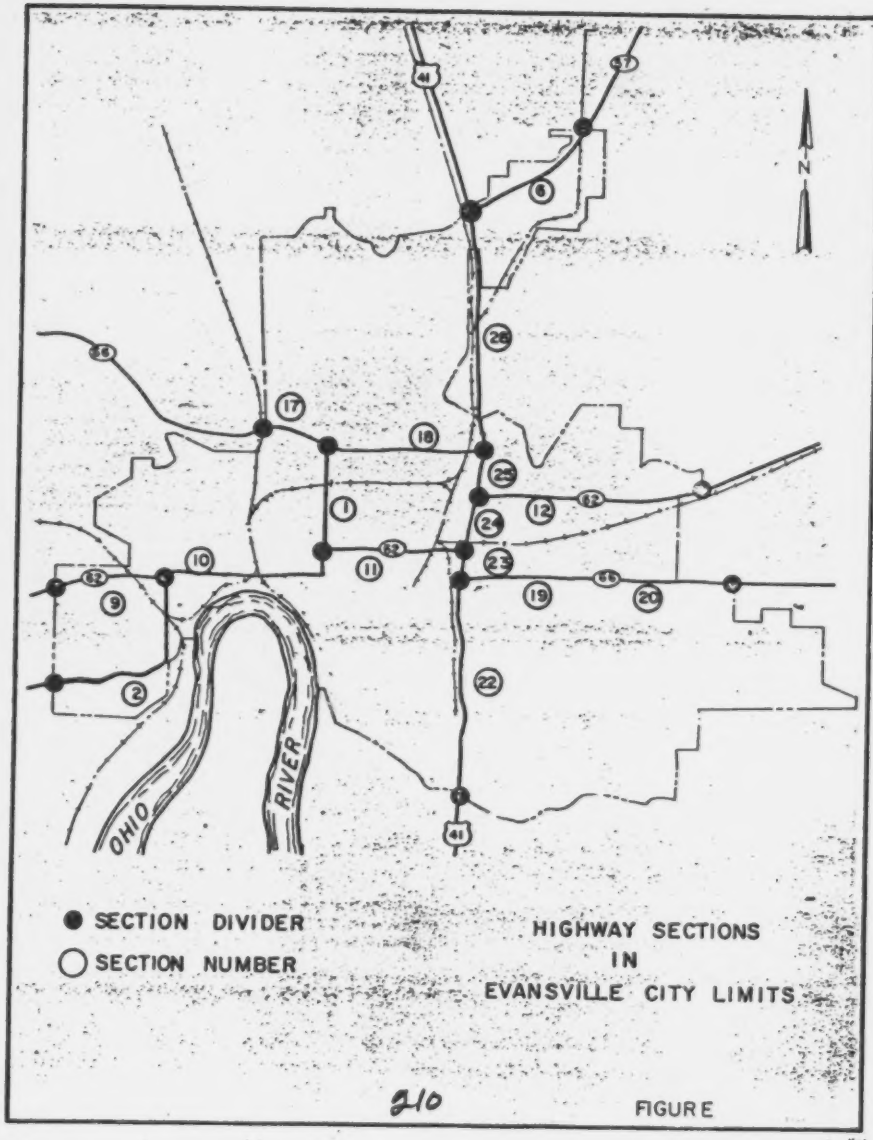
1 Probability that the route segment survives.

2 Sections with no structures:

6
8, 11, 12, 13
17, 20
22, 24, 25
SR57
SR62
SR66
US41



EVANSVILLE



3. Docks (River Ports)

Due to the generally unfavorable soil conditions which are typical for the river bank locations of port and dock facilities, it is expected that these facilities will not be available for use in Evansville following an occurrence of the CUSEPP planning earthquake. Figure _____ shows the location of river port and dock facilities for Evansville.

4. Airports

As discussed in the general section on airports, (Section III.B.3.c.4.) airport runways will ^{generally} be at least partially available for use in Evansville following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for others in the area of similar structural type. Figure _____ shows the location of major airport facilities for Evansville.

FIGURE _____

Location of River Ports

and

Airports

- this material to be supplied for Final Draft -

d. Public Utilities

1. Electric Utilities

General

The Southern Indiana Grand Electric Company (SIGECU) serves Evansville, population 140,000. SIGECO has approximately 800 full time employees, 118 radio equipped vehicles, four branch offices with main office in Evansville. SIGECO has five generating stations, all of which are not located in Evansville, one standby reserve, fourteen bulk power stations (no spare transformer), eighty seven distribution stations (150 MVA reserve station equipment) and four mobile substations. SIGECO has five major transmission interconnections with other electric utilities. Figure _____ depicts major elements of the Evansville system.

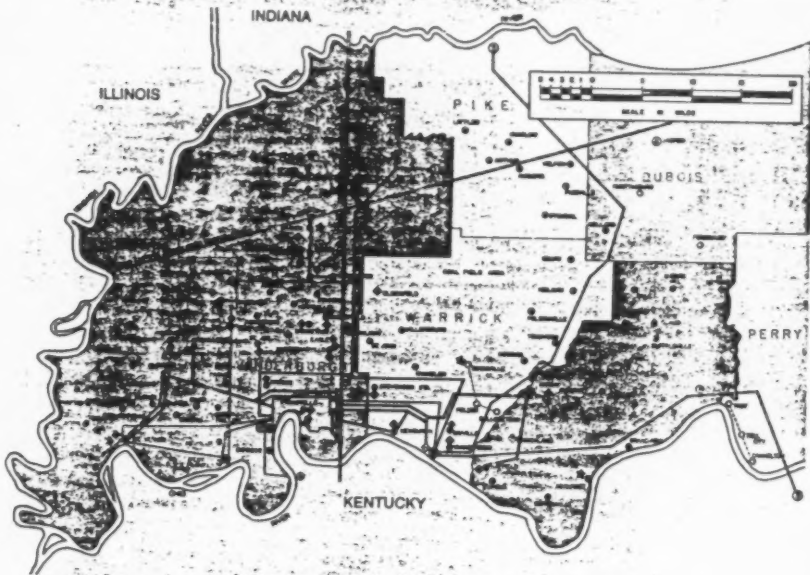
Availability Analysis

Table _____ presents the results of the availability analysis. Fragility techniques and system factors indicate that damage to this utility system will be significant, and that it is probable that it will not be available following an occurrence of the project earthquake.

TABLE _____
 Availability of Electric Utilities
 Evansville

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 11	7/64%	—
Power Plants <u>1</u>	<u>0/0%</u>	—
TOTAL 12	7/58%	—
		No

SIGECO'S Business and Service Area



The Company is engaged in the generation, transmission, distribution and sale of electricity in a southwestern Indiana region of about 2,250 square miles, with a population estimated to be nearly 350,000. Electric service is supplied directly to Evansville and 74 other cities, towns and communities, and adjacent rural areas. Wholesale electric service is supplied to an additional 8 communities. The Company serves 100,880 electric customers.

The Company is also engaged in the purchase, distribution and sale of natural gas in Evansville and 22 other nearby communities and their environs. Gas service is supplied to 61,293 customers. Prior to 1978, natural gas was purchased exclusively from Texas Gas Transmission Corporation under a 17-year Service Agreement dated September 1, 1970. The gas supply for the Ft. Branch Natural Gas Company system, acquired in 1978, is purchased from Texas Eastern Transmission Corporation.

For the year ended December 31, 1979, electric revenues accounted for 75.1% and gas revenues were 24.9% of total operating revenues.

Legend

- Electric Service — Retail
- Electric Service — Wholesale
- ◆ Gas Service — Retail
- ◆ Steam Electric Plant
- ◆ Gas Turbine Electric Peaking Plant
- ① Interconnection with Public Service Indiana
- ② Interconnection with Louisville Gas and Electric Company
- ③ Interconnection with Indianapolis Power & Light Company
- ④ Interconnection with Indiana Statewide Rec. Inc.
- ⑤ Interconnection with Big Rivers Electric Corporation
- ⑥ Interconnection with The City of Jasper, Indiana (60KV)
- ◆ Interconnection with ALCOA'S Steam-Electric Generating Station
- Electric Lines of SIGECO — 138KV
- Electric Lines of Wholesale Customers
- Gas Pipelines — SIGECO
- Pipeline Metering Points
- Gas Pipelines other Companies
- Oliver Gas Storage Field
- Midway Gas Storage Field
- ★ District Offices

2. Water Utility

General

The City of Evansville's main source of water is the Ohio River. The water treatment plant has the capacity to treat 60 MGD. In addition, the city operates a 1.5 MGD deep well as an auxiliary source of water. The water treatment plant operations include sedimentation, coagulation, filtration, and chlorination. A network of water mains ranging in size from 2 inches to 48 inches distribute water to the water service area. Booster pumping stations are located throughout the city, particularly in the outlying areas. Water storage consists of both elevated tanks and underground reservoirs. Underground storage includes the 6 MG reservoir at the water treatment plant and the 20 MG Stringtown Reservoir. The elevated tanks are dispersed throughout the city, typically having a capacity of 100,000 gallons. Booster pumping stations are often located near the storage tanks. Figure _____ shows the water treatment plant, storage facilities, and booster pumping station locations.

Availability Analysis

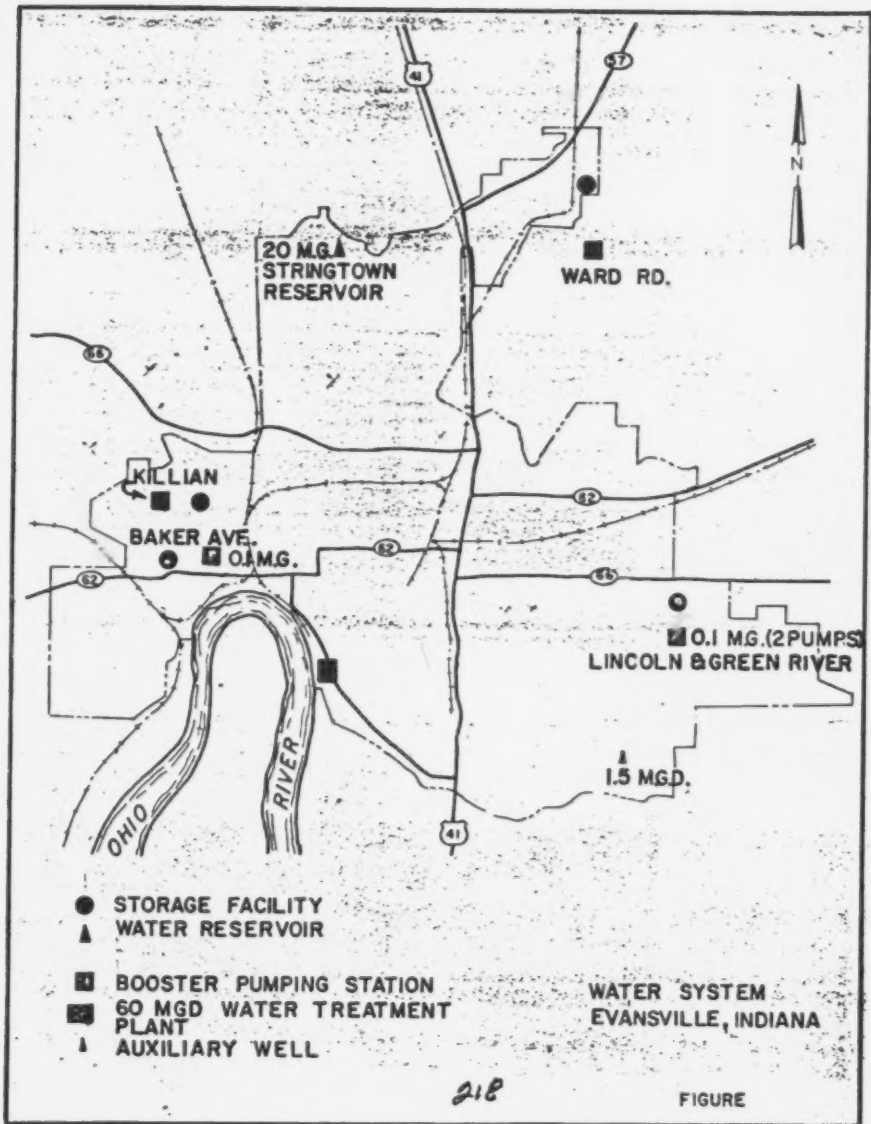
Table _____ presents the findings of the availability analysis. Damage to system elements and distribution system, coupled with the expected loss of electric power make it likely that this system would not be available following an occurrence of the project earthquake.

Availability Analysis

Water Utility

Evansville

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>System Availability (Yes/No)</u>
Treatment Plants: 1	0/0%	—
Storage Tanks elevated: 3	10/33%	—
Non-elevated: 2	2/100%	—
Pump Stations 4	<u>3/50%</u>	—
TOTAL 10	5/50%	—
		No



3. Natural Gas Utility

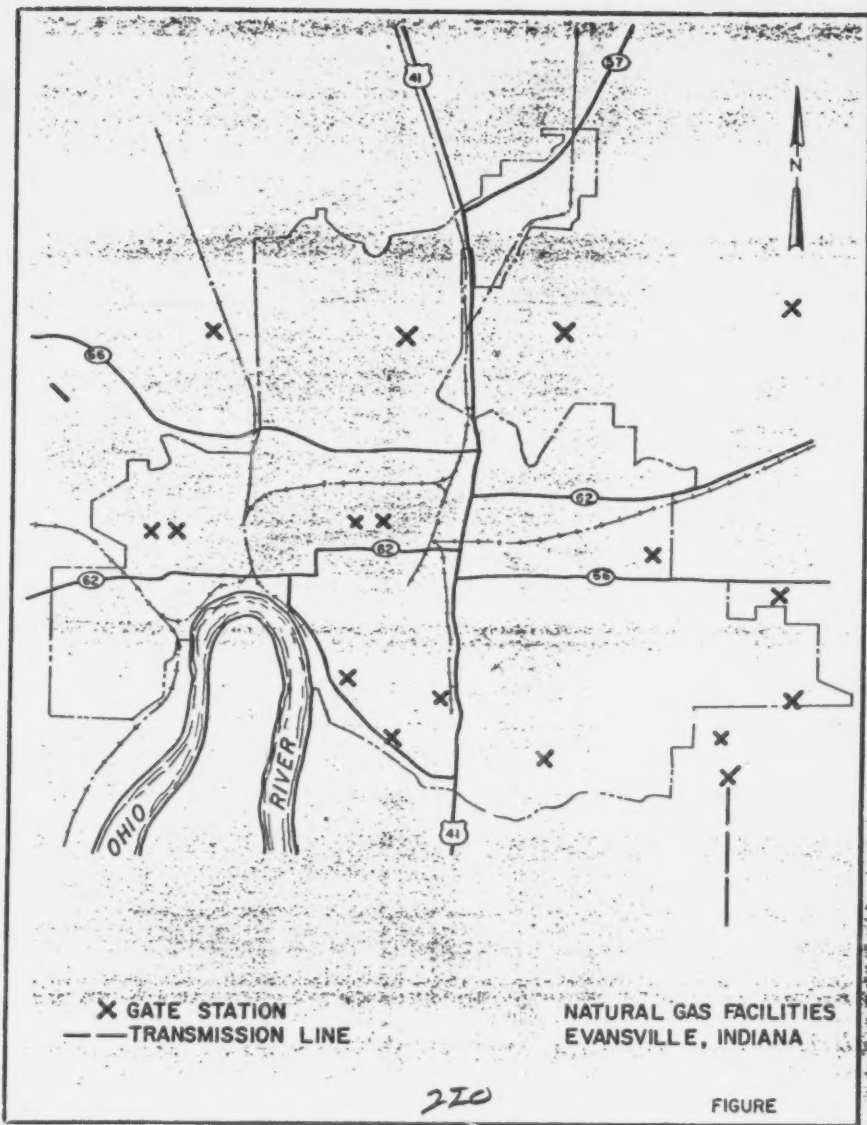
The natural gas system of Evansville, Indiana is owned by Southern Indiana Gas & Electric Company. The system has two (2) purchase points and buys its gas from Texas Gas Transmission Company. There is no propane-air or LNG plants in the system. Eight hundred sixty five (865) miles of steel, plastic and cast iron piping make up the system.

The cast-iron piping in the system would crack and rupture in many places in the event of any substantial earth movement in Evansville. Additionally, some damage to service piping and meter sets would occur from buildings and debris hitting these items.

The natural gas system serving Evansville would have to be shut down immediately following a major quake. Small sections of the system could be restored in twenty four hours to provide heat for a few selected shelter areas. The remainder of the system would have to be restored on a customer by customer basis. This process should take three to four weeks.

Availability Analysis

As discussed above, this system is expected to be unavailable following the project earthquake.



4. Sewage System

General

The Evansville Sewer Department provides wastewater treatment for the City of Evansville and Vanderburgh County. Both the Eastside wastewater treatment plant and the Westside wastewater treatment plant discharge treated wastewater into the Ohio River. The Eastside WWTP is an activated sludge facility with a design capacity of 18.0 MGD. The treatment plant operations include influent pumping, grit removal, clarification, aeration, chlorination, sludge digestion and vacuum filtration. The main line pumps are operated by V-8 engines which use natural gas or methane gas produced on-site. The methane is stored in a tank at the wastewater treatment plant. Standby pumping is provided by electrically operated pumps. The Westside WWTP has a design capacity of 20.6 MGD and is also an activated sludge system. The unit processes are essentially the same as those at the Eastside plant. The main line pumps are operated in the same manner as the Eastside WWTP. However, the Westside WWTP has an auxiliary generator which operates the cooling water jacket pumps on the V-8 engines. The Eastside plant has had no difficulty with overheating of pumps and therefore, has no auxiliary generator. Figure shows the location of each wastewater treatment plant.

The Sewer Department operates fifty-one (51) wastewater lift stations throughout Vanderburgh County. In addition, there are six (6) combined sewer overflow structures and two structures which allow stormwater ponding during heavy rains. The storm and sanitary wastewater collection systems are combined in Evansville and Vanderburgh County. The sewers range in size from 8-inch to 96-inch pipe. The older sewers in the center of the city are brick lined with concrete. The newer pipe is primarily concrete and plastic. The force mains are generally iron with some plastic pipe.

Availability Analysis

Figure _____ gives the results of the availability analysis for this system. The "conditional" negative finding for availability is based upon loss of all fueling/powering the main pumps at the waste treatment plants. If the pumps are operational, the system could have limited use. Collection system damage and loss of lift stations may be an added significant negative factor.

Availability Analysis

Sewage Systems

Evansville

Number of Structures
Surveyed

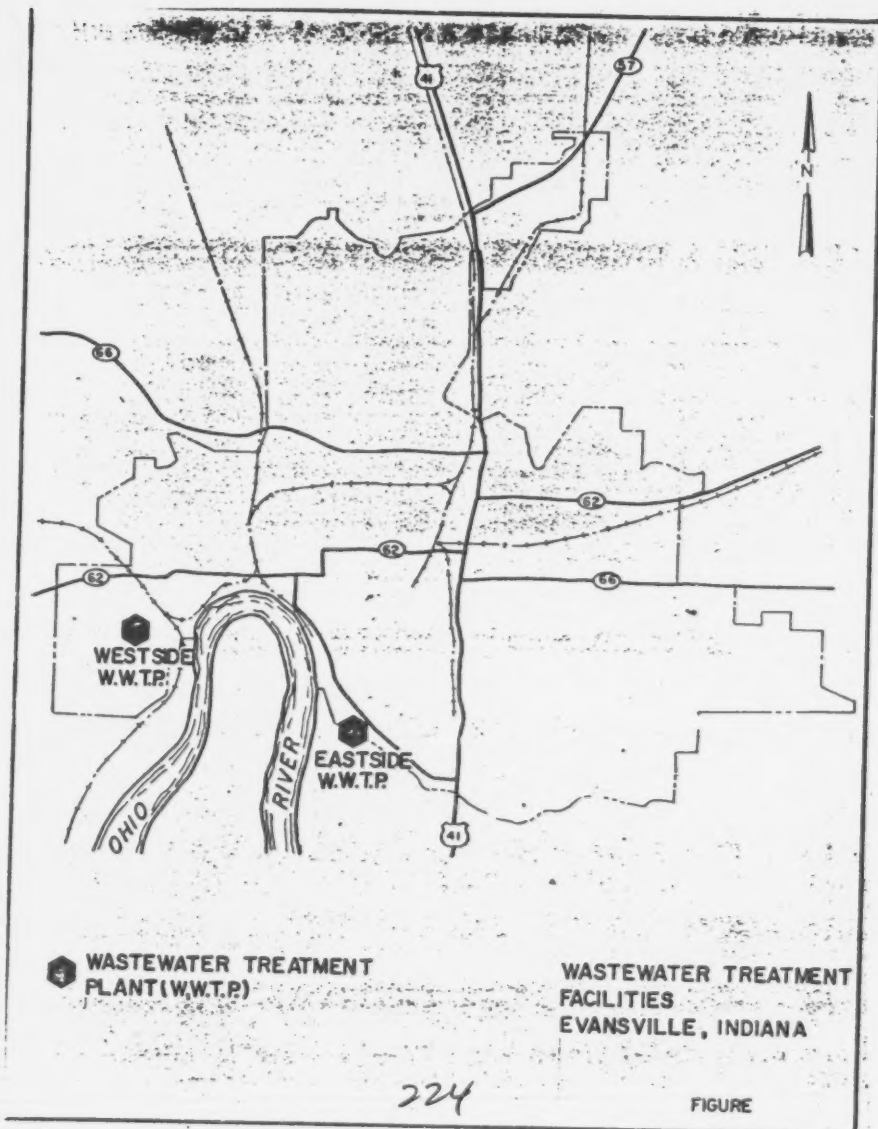
Treatment Plants 2

Structures Expected
To be Available

0/100%

System Availability
(Yes/No)

No (conditional)



5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.8.4. "Conflagrations"), following the general discussion of public utilities.

III.F. Paducah, General

The City of Paducah, located in western Kentucky on the south bank of the Ohio River, is the fourth most populous of the project cities. Paducah's 1980 population was approximately 29,000 persons. This city contains major resources in the areas of industry, commerce and education. Paducah is a significant regional transportation center.

Physiographic Description (from Hopper, et al, 1983; CUSEPP Report #82-3):

Paducah is situated in the upper part of the Mississippi Embayment that is also called the East Gulf Coastal Plain (Fenneman, 1938) and near the confluence of the Tennessee and Ohio Rivers. Topographic relief is low for most of the city; total difference between the Ohio River and outlying suburbs is about 150 feet (46 m).

Figure _____ shows the hypothetical ground shaking intensities expected in Paducah following an occurrence of the CUSEPP planning earthquake. Damage and disruption would be significant were Paducah to experience such ground motion. This is reflected in the findings of the project, presented in this section of the report.

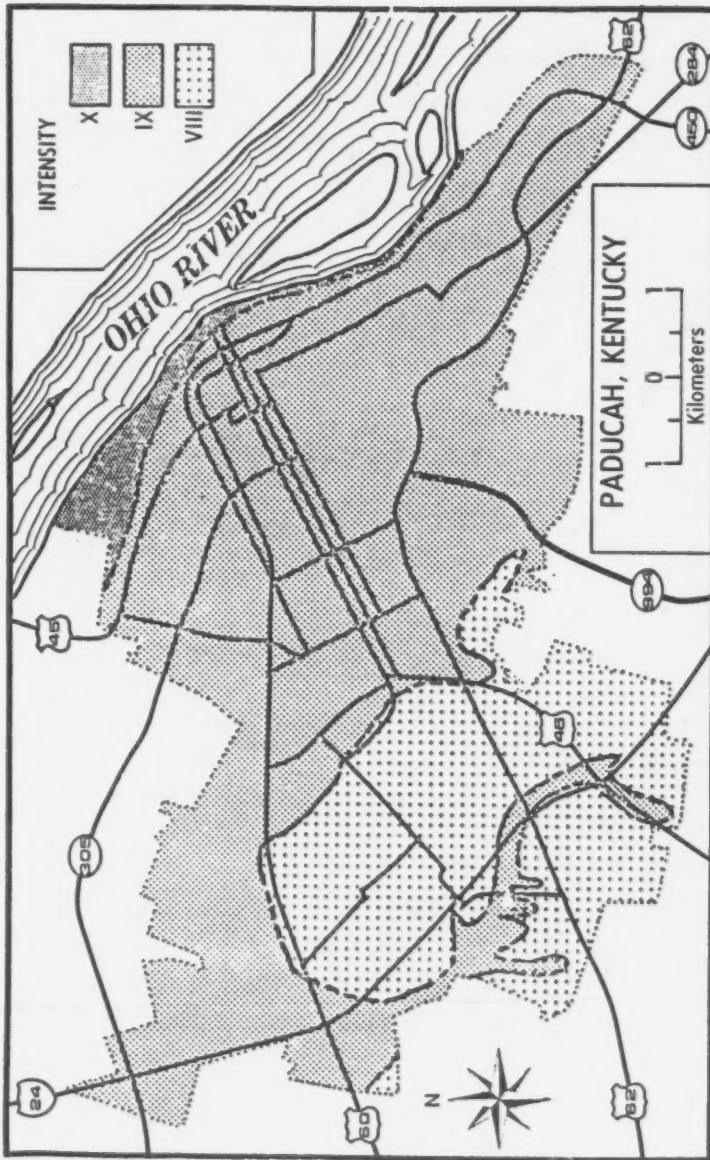


Figure — Hypothetical intensity map for Paducah, Kentucky. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Paducah are: X on the river alluvium, IX on the lacustrine deposits underlying most of the city, and VIII in the hills southwest of the city. For an earthquake near the south end of the New Madrid seismic zone, the intensities at Paducah would be lower.

From: Hopper, et al, 1983 (CUSEPP Report #82-3)

III.F.2. Effects on Medical Resources

Paducah possesses a full spectrum of medical services and facilities. These entities provide medical support to the city, surrounding communities and general region. Medical services surveyed during this project were: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

Two major hospitals, with seven major structures, serve Paducah. These general hospitals provide full service medical care, including emergency services. Both are equipped with emergency electrical generator. These facilities will be mostly available following the occurrence of the CUSEPP planning earthquake. Six of seven, or 86%, hospital structures and 723 (89%) of the total beds are expected to be available. Table _____ shows the results of the availability analysis for major hospitals in Paducah.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Paducah, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
2	7	811	6 / 86%	723 / 89%	Yes

III.F.2.c. Blood Banks

Availability of blood storage facilities in ^{Paducah} following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Paducah

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	2	2/100%
Non-Hospital:	<u>1</u>	<u>1/100%</u>
Total	3	3/100%

III.F.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Paducah following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospital's emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Paducah

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	2	2/100%
Other	<u>2</u>	<u>1/50%</u>
Totals	4	3/75%

III.F.2.e. Ambulance Services

The availability of ambulance service structures in Paducah following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Paducah

Number of Structures

Surveyed

9

Number Expected to

Be Available/Percent

6/67%

III.F.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

These findings, for the City of Paducah, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

As discussed earlier, in Section III.B.2.b., casualties from the failure of dams and levees are not expected to be significant and were not estimated. Persons displaced by flooding are enumerated in Table ____ presents the numbers of persons expected to be displaced by flooding due to levee failure, with the Ohio River and significant tributaries at the level of the 100 year flood. Figure ____ shows the area expected to be inundated. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given in Table ____ below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE
Displaced Persons and Available Shelter
Memphis

Flooding	Damage to Residences		Total	School Structures Available
	Single	Multi-Family		
5,254	6,318	7,000	13,318	5

TABLE
Availability of Police Services Structures
Paducah

Total Structures Surveyed	Structures Expected To Be Available/Percent
-0-	N/A

3. Schools



Paducah is alone among the project cities with respect to susceptibility to dam failure. This is due to the existence of two large reservoirs, Kentucky Lake on the Tennessee River, and Lake Barkely on the Cumberland River. Both these rivers enter the Ohio river a relatively short distance upstream from Paducah. Figure _____ illustrates this relationship. These reservoirs are retained with large earthen dams.

It was determined, for the purposes of this report, that the simultaneous failure of these dams, caused by an occurrence of the project earthquake at a time when there was a 100 year flood water level occurring on the Ohio River, was far too improbable to be realistically evaluated. Therefore, flooding due to levee failure was done as described above, and the effects of the simultaneous failure of the two large dams was evaluated assuming "normal" water levels in the Ohio, Tennessee and Cumberland Rivers. Two studies which are evaluating the effects of the failure of these dams are now underway by the Corps of Engineers and Tennessee Valley Authority; their results are not available.

However, indications are that, at "normal" river water levels, the failure of these dams would result in flooding, in Paducah, of a magnitude comparable to that of the 100 year flood.

III.F.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Paducah, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table _____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE _____

Availability of Fire Service Structures
Paducah

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
9	6/67%

2. Police Services

Table _____ shows the expected availability of police service structures in Paducah.

Table ____ shows the expected availability of school buildings, for use as shelter and for feeding large numbers of persons.

TABLE
Availability of School Structures
For Shelter Purposes
Paducah

<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
34	5/15%

b. Communications

Table ____ shows the expected availability of radio, television, and telephone structures in Paducah following the occurrence of the CUSEPP planning earthquake.

TABLE
Availability of Communications Structures
Paducah

	<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
Radio	4	2/50%
Television	1	1/100%
Telephone	—	—
Total	5	3/60%

Paducah is alone among the project cities with respect to susceptibility to dam failure. This is due to the existence of two large reservoirs, Kentucky Lake on the Tennessee River, and Lake Barkely on the Cumberland River. Both these rivers enter the Ohio river a relatively short distance upstream from Paducah. Figure ____ illustrates this relationship. These reservoirs are retained with large earthen dams.

It was determined, for the purposes of this report, that the simultaneous failure of these dams, caused by an occurrence of the project earthquake at a time when there was a 100 year flood water level occurring on the Ohio River, was far too improbable to be realistically

C. Transportation Systems

1. Railroads

Table _____ lists the survival probabilities for key rail links for Paducah. Maps defining rail network sections are shown in Figures _____ and _____.

Four of 21 of rail sections in Paducah have survival probabilities of less than 90%. The lowest, 69%, is part of the ICG-P&I link over the Ohio River. A failure in this link would adversely affect accessibility from the north.

Two below-criteria links (sections 1 & 21) provide all the rail accessibility from the east, but it is unlikely that both would fail.

The remaining weak link is within the city limits. Its loss would affect the network but not accessibility to the city.

TABLE III-3-5

PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN PADUCAH
WOULD SURVIVE NEW MADRID EARTHQUAKE

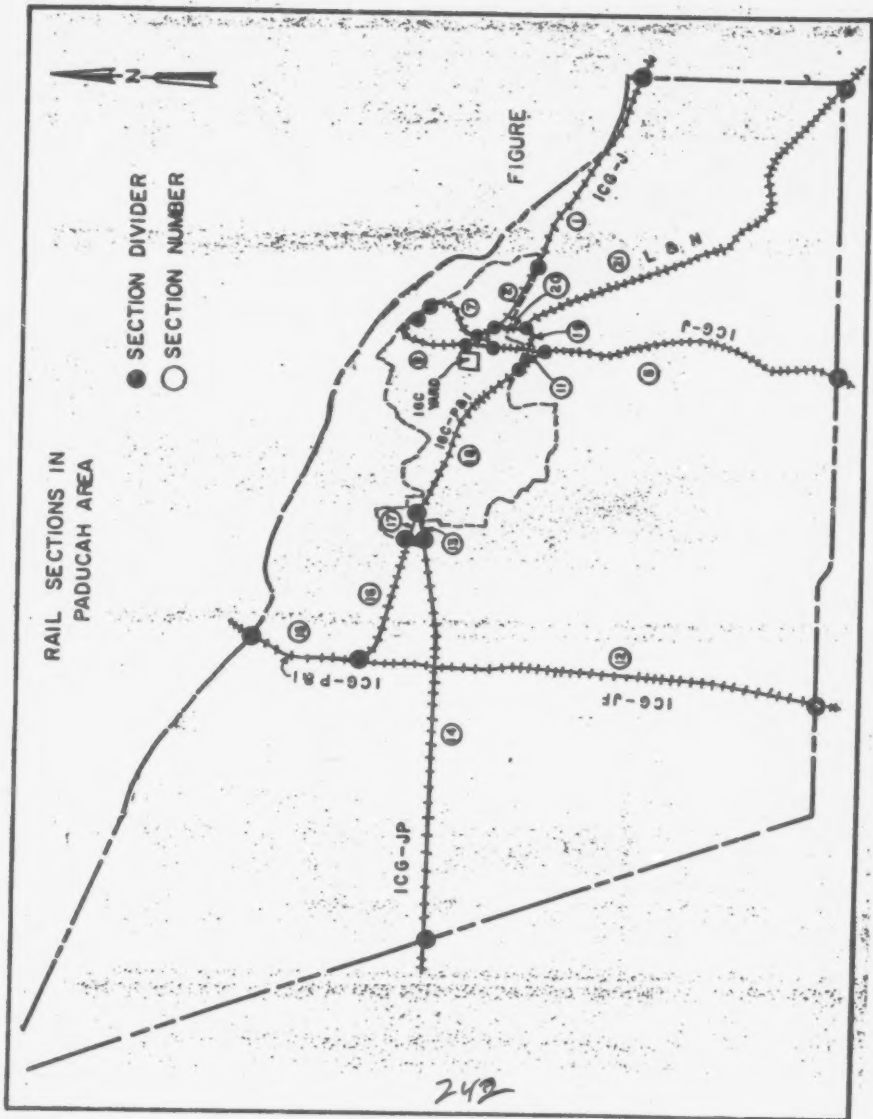
Section ²	Railroad Line	Number of Structures Supporting RR Line		Number of Structures Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs of Parallel Structures		Total Independent	Total Dependent
1	ICG-J	2	0	IX	.89	.96
2	ICG-J	2	0	IX	.92	.96
4	ICG-J	1	0	IX	.97	.98
5	ICG-J	5	0	VIII	.95	.99
6	ICG-J	0	0	IX	.99	.99
8	ICG-J	0	0	IX	.98	.98
12	ICG-JP	13	0	VIII	.90	.99
13	ICG-JP	0	0	IX	.98	.99
14	ICG-JP	6	0	VIII	.94	.99
15	ICG-P&I	2	0	IX/X	.69	.70
16	ICG-P&I	1	0	IX	.90	.96
17	ICG-P&I	0	0	IX	.90	.94
18	ICG-P&I	5	0	VIII/IX	.80	.94
19	ICG-P&I	1	0	IX	.96	.96
21	L&N	2	0	IX	.85	.94

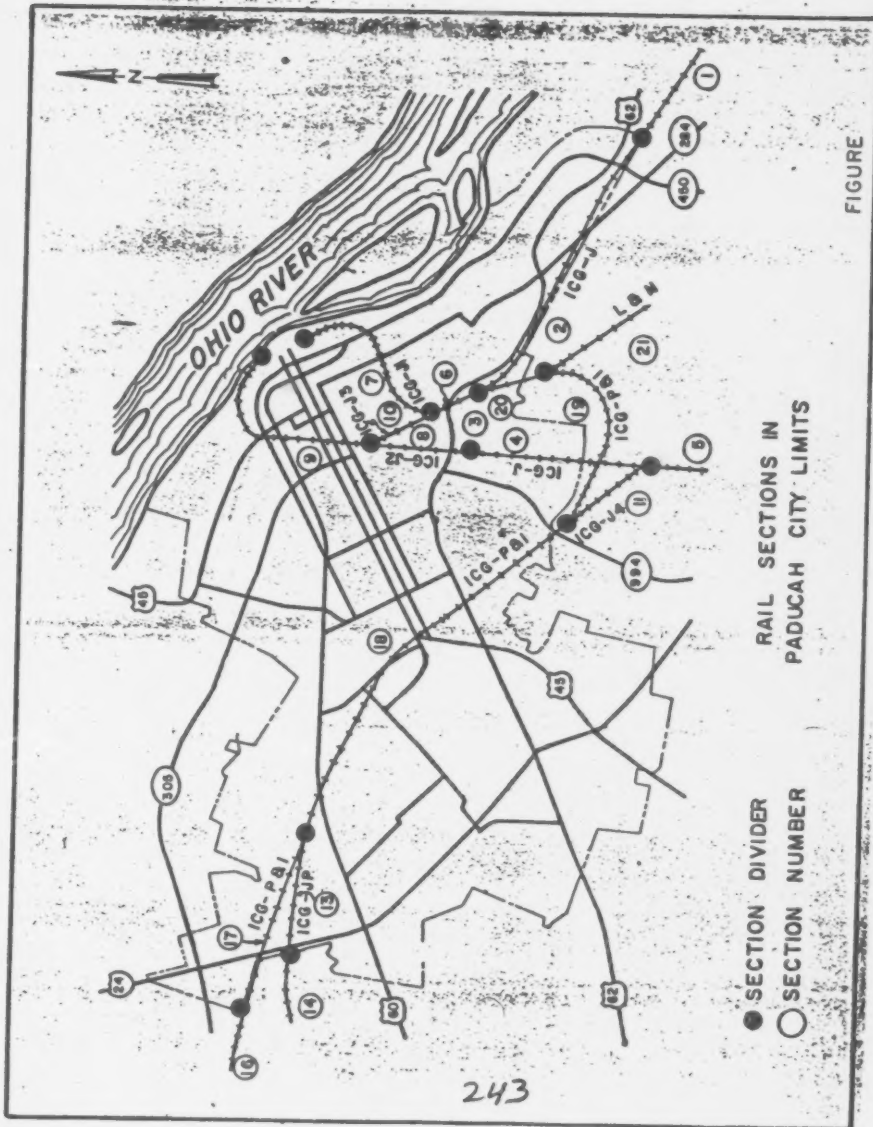
Notes:

1 Probability that the railroad line segment survives.

2 Sections with no structures:

3 ICG-J
7 ICG-J1
9 ICG-J2
10 ICG-J3
11 ICG-J4
20 ICG-P&I





2. Highways

Survival probabilities for Paducah's highways are shown in Table _____. Maps of key highway sections are shown in Figures ____ and _____.

Of the 50 highway sections analyzed, only six have survival probabilities of less than 90%. Three of these are on Route US 60 from the east. Since I-24 is a nonfragile alternative, damage on US 60 would not eliminate all accessibility, but it would clearly affect the capacity of traffic flows from the east.

Two other low-survival routes provide accessibility from the north. If they failed, the burden of accessibility would fall on Route 60, a low-survival route from the east. While failure of all these routes is unlikely, should it occur, accessibility from the north would be eliminated.

Except for US 60 (section 34), survivability of inner-city roads is good; thus, traffic flow should not be greatly impaired.

TABLE III-3-11

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN PADUCAH
WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Route	Number of Structures Supporting Route		Number of Structures Earthquake Over Route	Intensity	P (Survival)	
		Single Structures	Parallel Structures			Independent	Total Dependent
1	I24	1	1	0	IX/X	.70	.70
2	I24	0	3	0	IX	1.00	1.00
3	I24	0	3	0	VIII/IX	.99	1.00
4	I24	0	0	1	IX	.98	.98
5	I24	0	1	1	VIII/IX	1.00	1.00
6	I24	0	3	1	VIII	1.00	1.00
7	I24	0	3	4	VIII/IX	.94	.98
8	I24	0	0	1	IX	.98	.98
9	SR131	1	0	0	IX	.94	.94
10	SR131	1	0	0	IX	.94	.94
11	SR284	1	0	0	IX	.94	.94
12	SR305	1	0	0	IX	.94	.94
13	SR305	2	0	0	VIII	.97	.97
14	SR305	1	0	0	VIII	.98	.99
15	SR305	1	0	0	IX	.94	.94
17	SR358	1	0	2	IX	.92	.94
18	SR786	1	0	1	VIII	.99	.99
19	SR786	1	0	0	VIII	.99	.99
20	US15	2	0	0	VIII	1.00	1.00
22	US45	0	0	2	IX	.96	.98
23	US45	0	0	1	IX	.99	.99
26	US45	2	0	0	X	.30	.43
28	US60	6	0	0	VIII	.98	.99
29	US60	2	0	0	VIII	.97	.97
30	US60	1	0	0	VIII	.97	.97
31	US60	2	0	2	VIII/IX	.89	.94
34	US60	3	0	0	IX	.67	.74
36	US60	1	1	0	IX	.74	.74

TABLE III-3-11

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN PADUCAH (Continued)

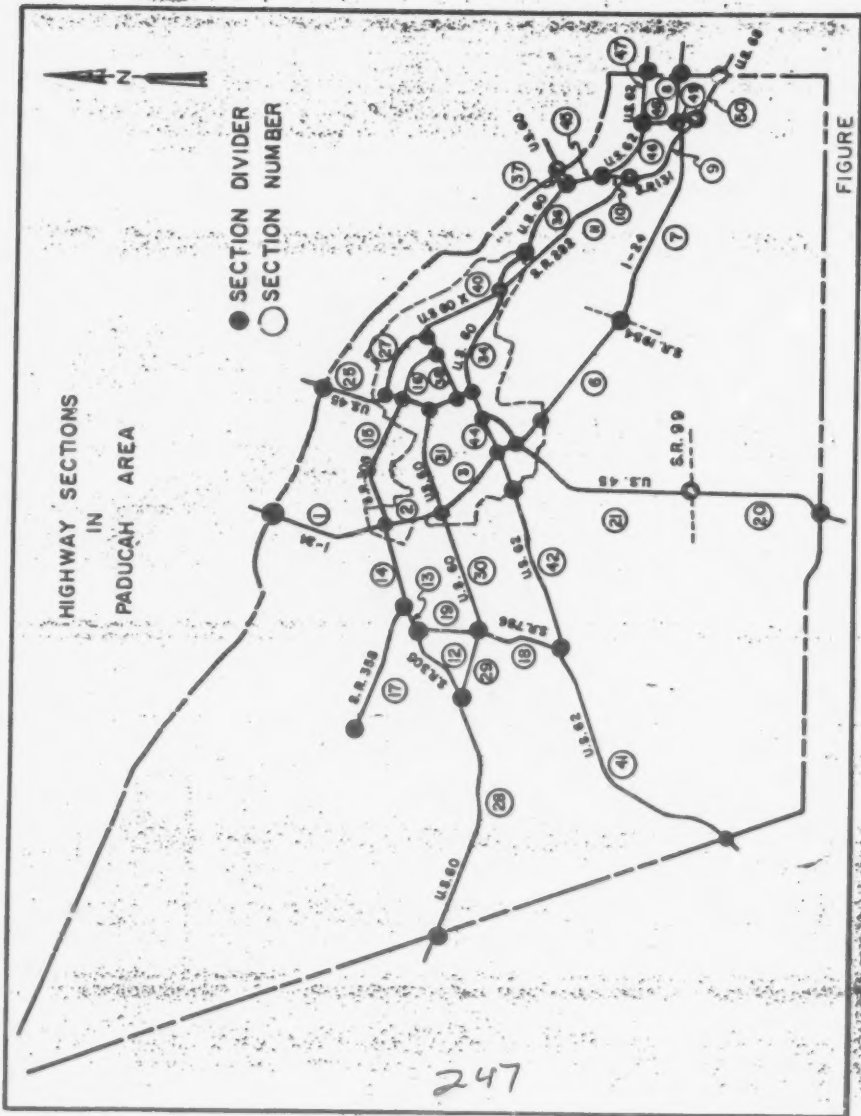
Section ²	Number of Structures Supporting Route		Number of Structures Over Route	Earthquake Intensity	P (Survival)	
	Route Structures	Parallel Structures			Total Independent	Total Dependent
37	US60	1	0	IX	.94	.94
40	US60X	1	0	IX	.94	.94
41	US62	1	0	VIII	.99	.99
42	US62	9	0	VIII	.91	.99
44	US62	1	0	IX	.94	.94
45	US62	0	1	IX	.78	.80
48	US68	2	0	IX	.92	.96

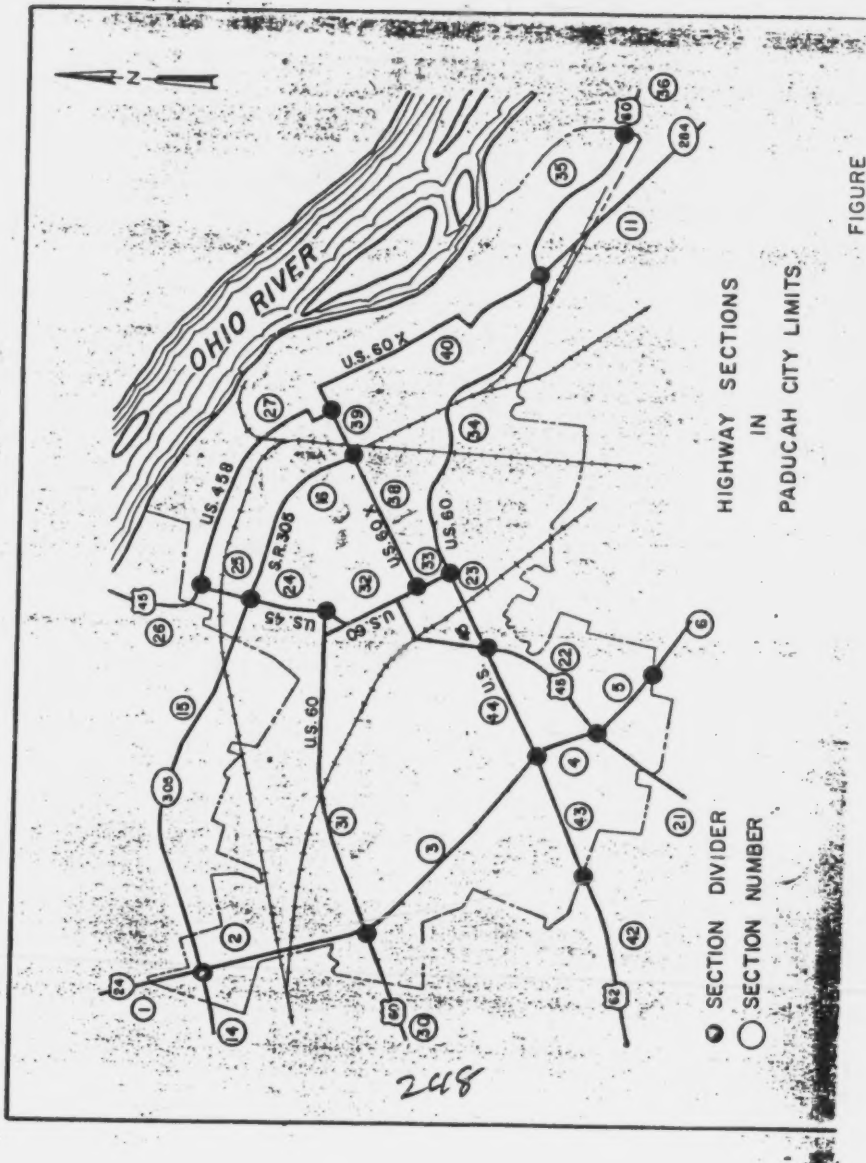
Notes:

1 Probability that the route segment survives.

2 Sections with no structures:

16 SR305
 21, 24, 25 US45
 27 US45B
 32, 33, 35 US60
 38, 39 US60X
 43, 46, 47 US62
 49, 50 US68





3. Docks (River Ports)

Due to the generally unfavorable soil conditions which are typical for the river bank locations of port and dock facilities, it is expected that these facilities will not be available for use in Paducah following an occurrence of the CUSEPP planning earthquake. Figure _____ shows the location ~~of~~ river port and dock facilities for Paducah.

4. Airports

As discussed in the general section on airports, (Section III.8.3.c.4.) airport runways will ^{generally} be at least partially available for use in Paducah following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for others in the area of similar structural type. Figure _____ shows the location of major airport facilities for Paducah.

FIGURE _____

Location of River Ports

and

Airports

- this material to be supplied for Final Draft -

d. Public Utilities

1. Electric Utilities

General

Paducah Power System (PPS) serves the city of Paducah and vicinity, population 42,000. PPS has seven distribution substations served from two TVA 161/69 kV delivery points. A 69 kV transmission loop serves these substations. PPS has two distribution substations, 73 employees and 22 radio equipped vehicles. PPS would also have access to TVA's mobile facilities.

TVA's Shawnee steam generating plant is also located in Paducah. Shawnee has 480 employees, total generating capacity of 1,750 MW and is coal fired. Figure _____ shows major elements of the Paducah electric utility system.

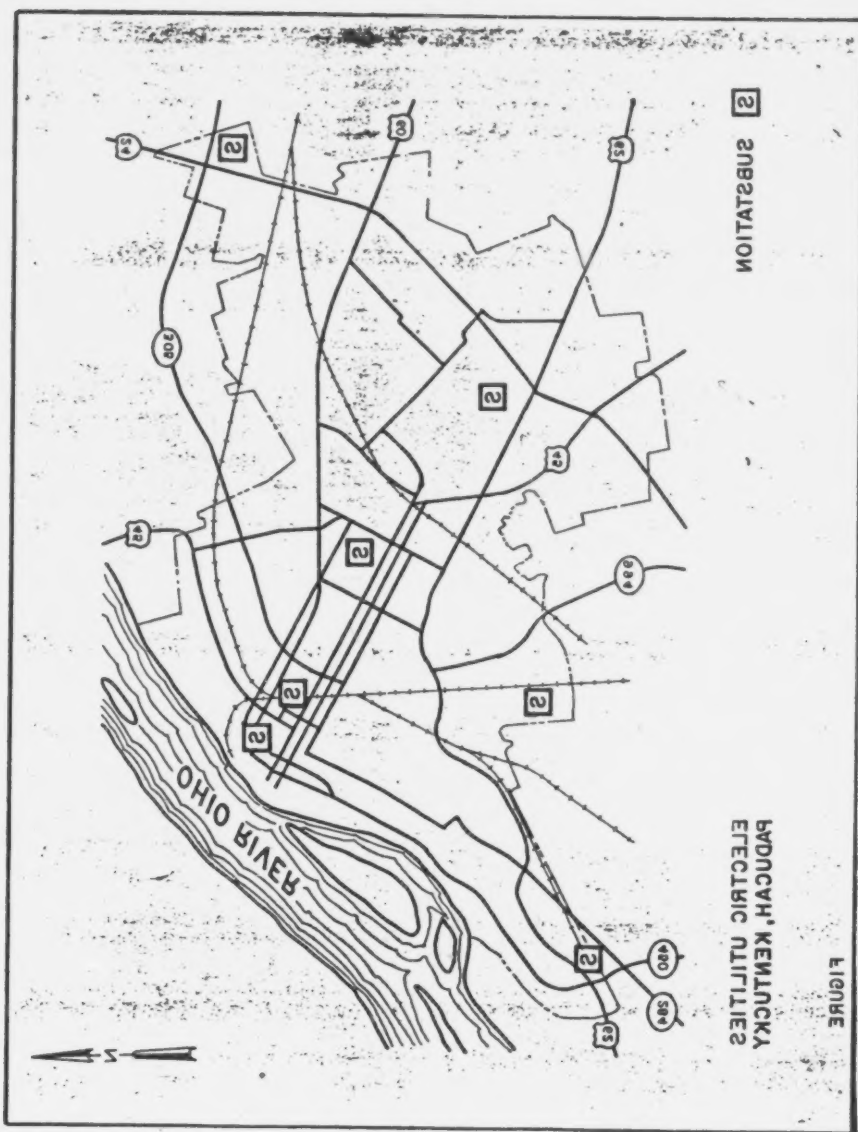
Availability Analysis

Table _____ shows the results of the availability analysis performed for Paducah's electric utility. The findings indicate that damage would be extensive, to both the power plant and to substations. The system is not expected to be available following the project earthquake.

TABLE _____
Availability of Electric Utilities

Paducah

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 7	3/38%	_____
Power Plants 1	<u>0/100%</u>	_____
TOTAL 8	3/38%	No



2. Water Utility

General

The Paducah Water Works Department operates a 12 MGD water treatment plant built in the 1800's. A new 12 MGD treatment plant which was designed for seismic loading is under construction and should be on-line in early 1984. Within six months to a year the old plant will be abandoned. The source of raw water is the Ohio River. Treatment operations at both the existing and future plant consist of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination. The existing water treatment plant has a gasoline powered auxiliary engine which powers only a portion of the plant during an electrical outage. The new water plant will have an emergency generator which will operate the entire plant. Figure _____ shows the locations of both water treatment plants.

Paducah has 11.3 MG of water storage capacity composed of four standpipes and one reservoir. The capacity of each storage facility is listed in Table _____. The water storage locations are indicated in Figure _____.

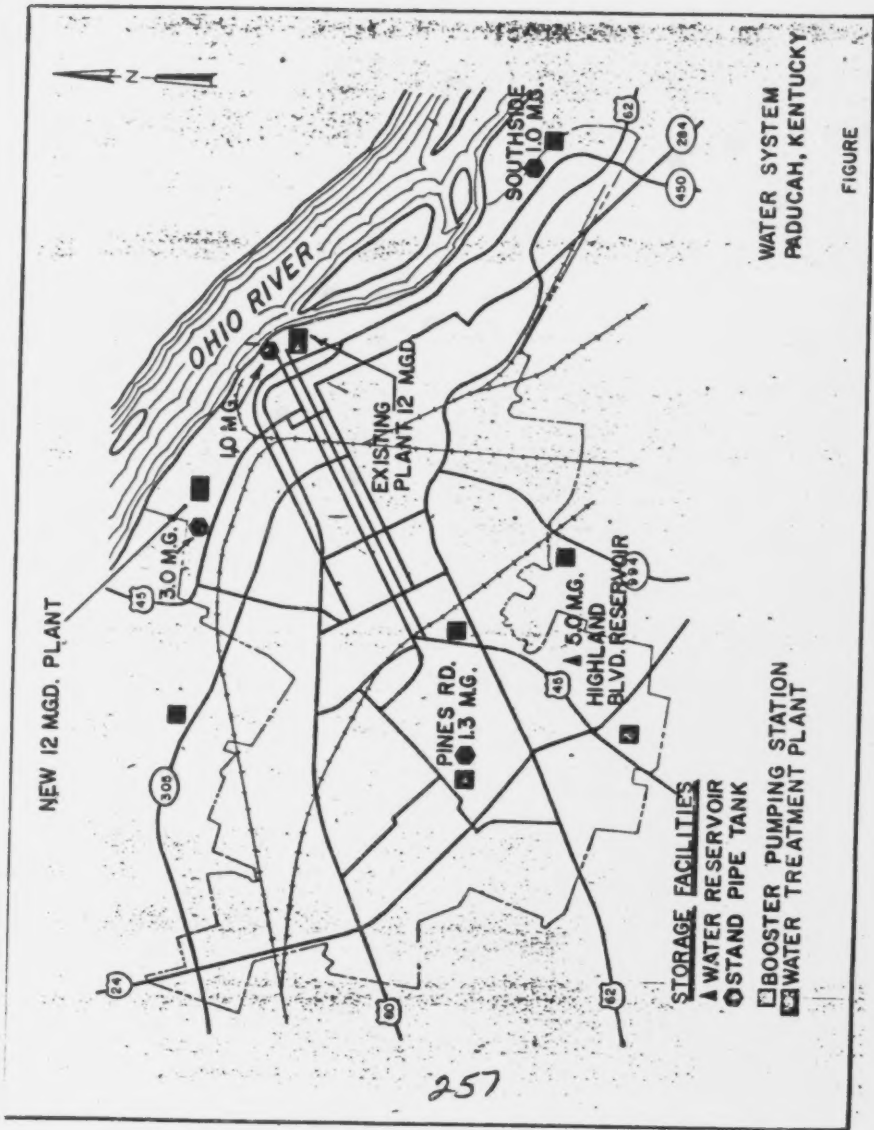
The water distribution system includes water mains ranging from 2 to 30 inches in diameter. The majority of the pipe is cast iron. The 30-inch pipe from the new water plant to the Pines Road tank is concrete. Some subdivisions which have been annexed by the Paducah system may have plastic pipe. There are four booster pumping stations located in the outlying portions of the service area. Both the Pines Road and Southside standpipes have booster pumps.

Availability Analysis

Table _____ presents the results of the availability analysis for Paducah. Due to the damage likely to be sustained to the treatment plant and pump stations, the lack of elevated storage and probable loss of electric power, this water system is expected to be unavailable following an occurrence of the project earthquake.

Availability AnalysisWater UtilityPaducah

<u>Total Number of Structures Surveyed</u>		<u>Structures Expected To be Available/Percent</u>		<u>System Availability (Yes/No)</u>	
Treatment Plants: 1		0/0%		_____	
Storage Tanks non-elevated 4		4/100%		_____	
Pump Station 6		2/33%		_____	
TOTAL 11		6/55%		_____	
				NO	



3. Natural Gas Utility

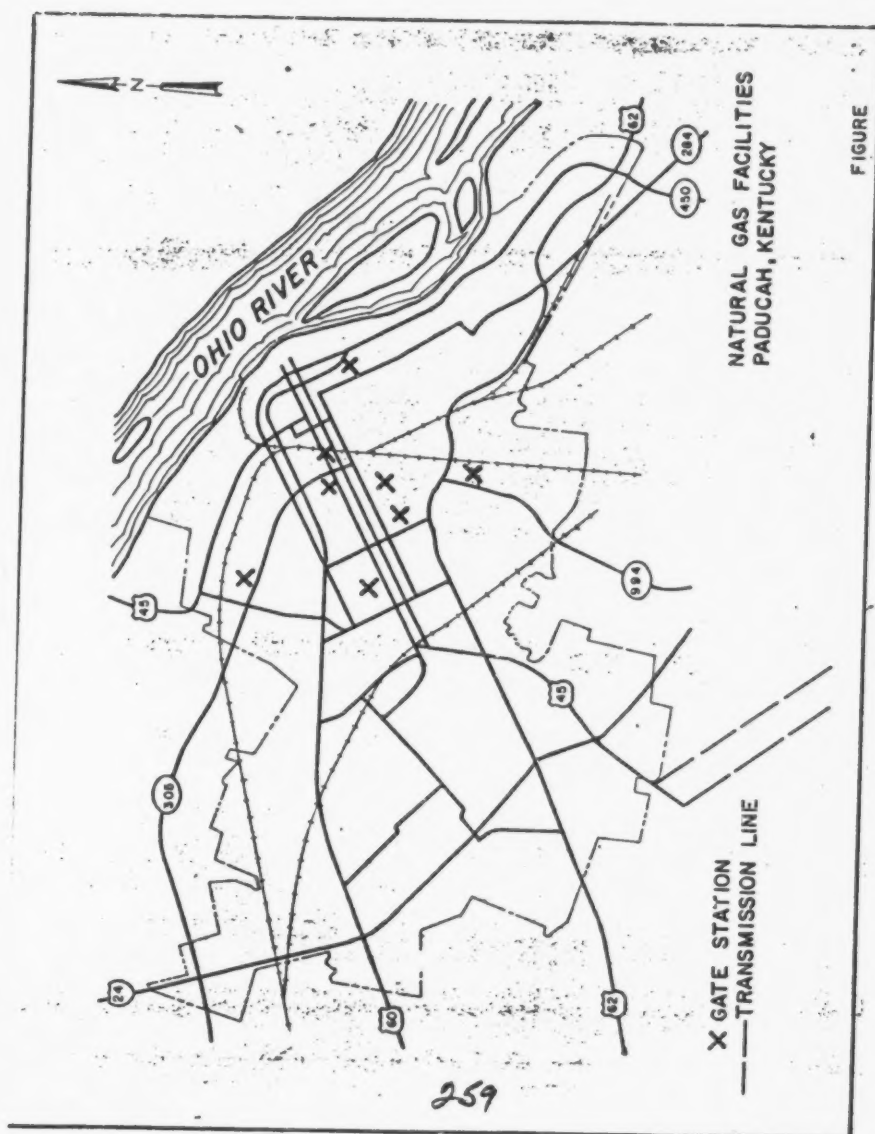
The natural gas system of Paducah, Kentucky is operated by Western Kentucky Gas Company. The system has one (1) purchase point with 41 district and town border regulator station points. It buys it's gas from Texas Gas Transmission Company. There are no storage facilities for propane-air or LNG. Approximately, forty (40) miles of piping make up the system, most of which is steel with the remaining piping being cast iron or plastic.

The cast-iron piping in the system would crack and rupture in many places in the event of any substantial earth movement in Paducah. Additionally, some damage to service piping and meter sets would occur from buildings and debris hitting meter sets.

The natural gas distribution system serving Paducah would have to be shut down immediately following a major quake. Small sections of the system could be restored in twenty four hours to provide heat for a selected shelter. The remainder of the system would have to be restored on a street by street, customer by customer basis. This process would take about four weeks. Figure _____ shows major system elements.

Availability Analysis

As described above, this system is expected to be unavailable following the project earthquake.



4. Sewage System

General

The Paducah Sewage Treatment Department serves the City of Paducah with an 8 MGD activated sludge wastewater treatment plant. The treatment processes include an influent pump station, grit chambers, primary settling tanks, aeration basins, secondary settling tanks, chlorine contact tanks, and sludge treatment facilities. The treated wastewater is discharged into the Ohio River. There are no emergency power facilities. The location of the wastewater treatment plant is shown in Figure ____.

There are twenty-four lift stations located throughout the city. Pumping capacities range from 50 gpm to 900 gpm. The sanitary and storm wastewaters are combined in Paducah. Sanitary sewers are 8 inches to 102 inches in diameter and storm sewers range from 12 inches to 102 inches. The sewer pipes are primarily clay. However, there is some concrete pipe and very little plastic pipe.

Availability Analysis

As shown in Figure ____, this system is not expected to be available following the project earthquake. This is due to the probable loss of electric power, collection system damage and damage to the treatment plant.

Availability Analysis

Sewage Systems

Paducah

Number of Structures
Surveyed

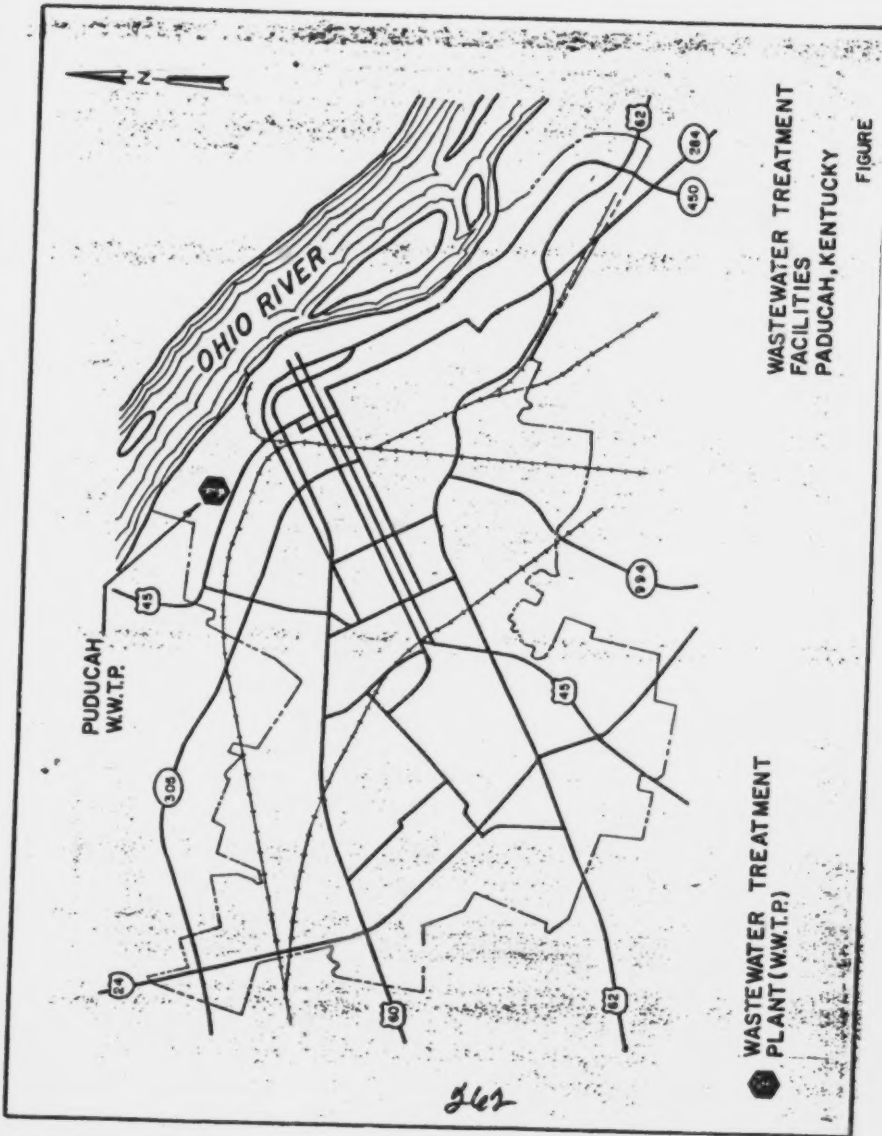
Treatment Plants 2

Structures Expected
To be Available

0/100%

System Availability
(Yes/No)

No



5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.6.4. "Conflagrations"), following the general discussion of public utilities.

III.H. Carbondale; General

The City of Carbondale, located in extreme southern Illinois, is the fifth-most populous of the six project cities. The population of Carbondale in 1980 was approximately 26,000 persons. Carbondale is a major factor in the economy of southern Illinois, contributing in the areas of coal, agriculture, commerce and education, being the site of Southern Illinois University.

Physiographic Description (from Hopper, et al, 1983; CUSEPP Report #82-3):

Carbondale is situated in the till plains of the Central Lowland province (Fenneman, 1938) in an area of very low topographic relief.

Figure _____ shows the hypothetical intensities of ground shaking to be expected in Carbondale following an occurrence of the CUSEPP planning earthquake. These levels of ground motion will cause significant disruption in this city. The findings of the project's analyses are presented in this section of the report.

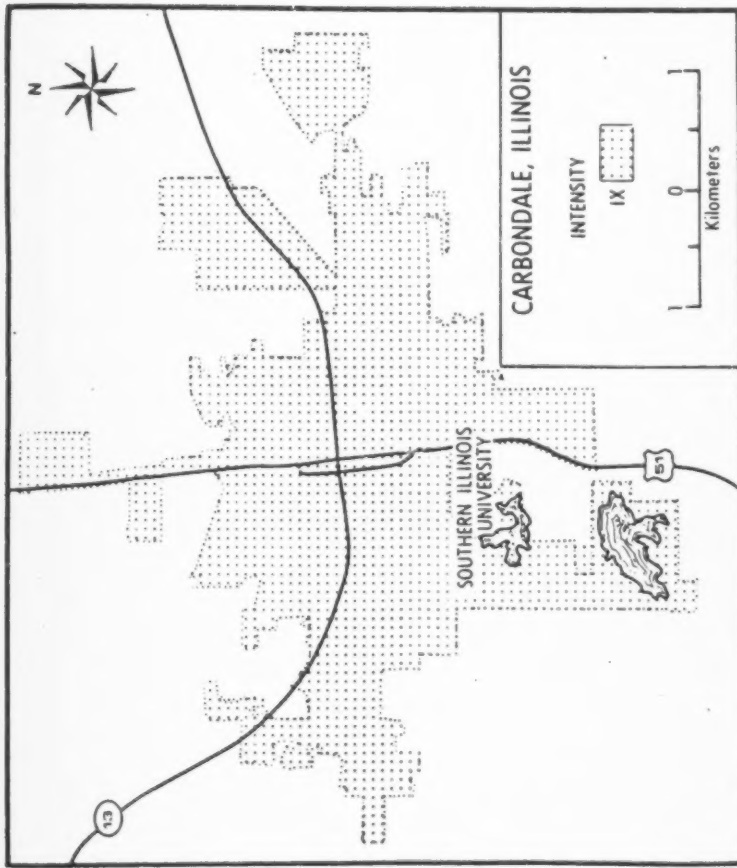


Figure 1. Hypothetical intensity map for Carbondale, Illinois. For an earthquake near the north end of the New Madrid seismic zone, the intensity for Carbondale is IX for the entire city. For an earthquake near the south end of the New Madrid seismic zone, the intensity at Carbondale would be lower.

from: Hopper, et al, 1983 (CUSEPP Report #82-3)

III.6.2. Effects on Medical Resources

Carbondale possesses a full spectrum of medical services and facilities. These entities provide medical support to the city, surrounding communities and general region. Medical services surveyed during this project were: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

Carbondale is served by one major hospital with six major structures, which were surveyed for the project. This full service general health care facility incorporates a diesel powered electric generator which supplies emergency power to a large number of areas and operations essential to hospital operation.

Moderate disruption of this facility is indicated following occurrence of the project earthquake. Five of six major structure (83%) are expected to be available, which correspond to 187 (94%) availability of hospital beds. The emergency power system is also likely to be available. Table _____ present these findings.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Carbondale, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE _____
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
1	6	200	5 / 83%	187 / 94%	Yes

III.G.2.c. Blood Banks

Availability of blood storage facilities in *Carbondale* following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Carbondale

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	1	1/100%
Non-Hospital:	<u>Non Surveyed</u>	<u>-</u>
Total	1	1/100%

III.6.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Carbondale following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospitals emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Carbondale

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	1	1/100%
Other	<u>0</u>	<u>0</u>
Totals	1	1/100%

III.G.2.e. Ambulance Services

The availability of ambulance service structures in Carbondale following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Carbondale

<u>Number of Structures</u>	<u>Number Expected to</u>
<u>Surveyed</u>	<u>Be Available/Percent</u>
11	7/64%

evaluated. Therefore, flooding due to levee failure was done as described above, and the effects of the simultaneous failure of the two large dams was evaluated assuming "normal" water levels in the Ohio, Tennessee and Cumberland Rivers. Two studies which are evaluating the effects of the failure of these dams are now underway by the Corps of Engineers and Tennessee Valley Authority; their results are not available.

However, indications are that, at "normal" river water levels, the failure of these dams would result in flooding, in Paducah, of a magnitude comparable to that of the 100 year flood. III.G.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

These findings, for the City of Carbondale, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

Carbondale is not expected to be affected by flooding following an occurrence of the CUSEPP planning earthquake. No casualties or displaced persons are expected due to flooding. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given in Table____ below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE
Displaced Persons and Available Shelter
Memphis

Flooding -0-	Damage to Residences		Total	School Structures Available
	Single	Multi-Family		
	3,003	2,725	5,728	17

III.G.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Carbondale, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table ____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE ____

Availability of Fire Service Structures
Carbondale

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
11	7/64%

2. Police Services

Table ____ shows the expected availability of police service structures in Carbondale.

TABLE Availability of Police Services Structures Carbondale	
<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
86	17/20

b. Communications

Table ____ shows the expected availability of radio, television, and telephone structures in Carbondale following the occurrence of the CUSEPP planning earthquake.

TABLE Availability of Communications Structures Carbondale		
	<u>Total Structures</u> <u>Surveyed</u>	<u>Structures Expected</u> <u>To Be Available/Percent</u>
Radio	7	5/71%
Television	-	-
Telephone	3	2/67%
Total	10	7/70%

C. Transportation Systems

1. Railroads

The probabilities of survival of key rail bridges in Carbondale are shown in Table _____. The maps of key rail sections are shown in Figures ____ and ____.

Seven of 13 rail links have survival probabilities of less than 90% but only section 11, MOPAC-EW from the west, has a seriously low survival probability: 53%. This and three other sections (5, 10, and 13) dominate rail accessibility from the west which would be eliminated if all failed. Such a combined failure is unlikely.

In general, impaired accessibility from the west may pose a problem, but useable rail connections from one or all of the other direction are expected to survive the project earthquake.

TABLE III-3-1

PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN CARBONDALE
WOULD SURVIVE NEW MADRID EARTHQUAKE

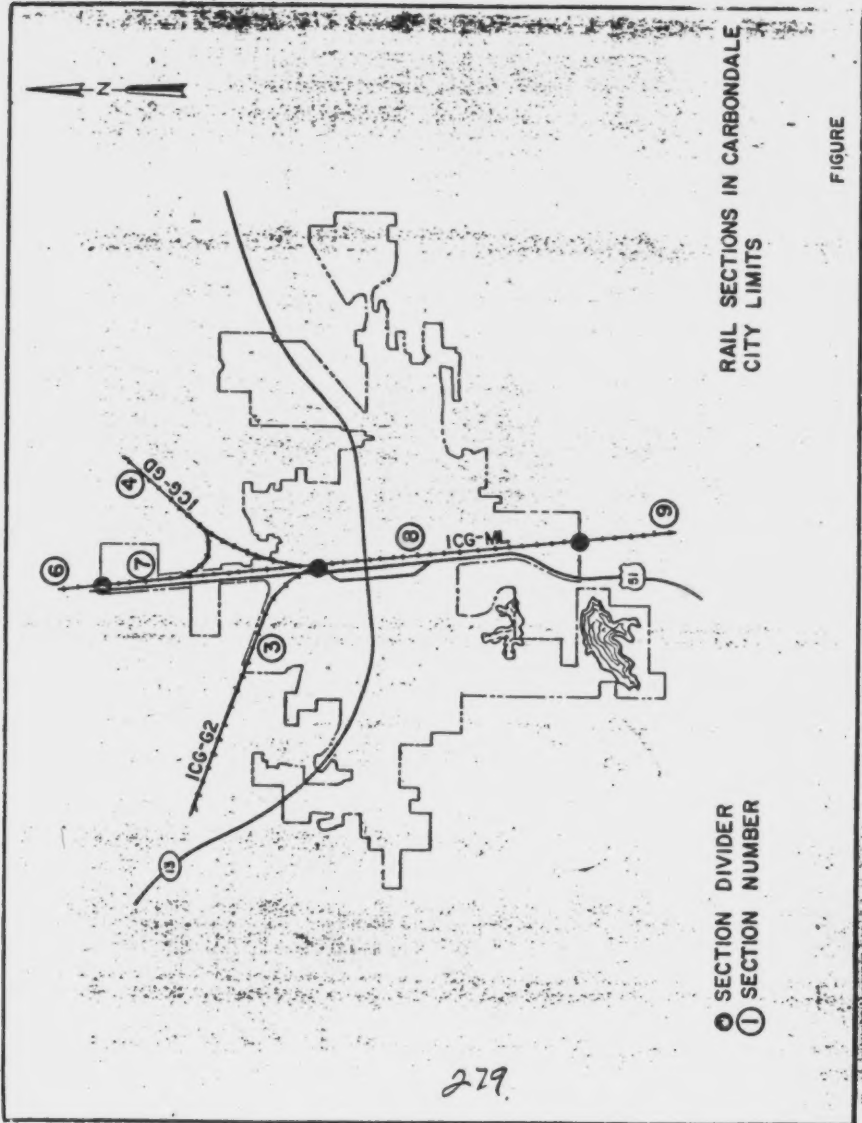
Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs Of Parallel Structures			Total Independent	Total Dependent
1	ICG-G1	5	0	0	IX	.77	.94
2	ICG-G2	4	0	2	IX	.80	.94
3	ICG-G2	3	0	1	IX	.91	.96
4	ICG-GD	3	0	0	IX	.88	.96
5	ICG-GM	6	0	0	IX	.80	.96
6	ICG-ML	4	1	2	IX	.90	.94
9	ICG-ML	2	0	0	IX	.96	.98
10	ICG-MM	7	0	1	IX	.78	.96
11	MOPAC-EW	16	0	0	IX	.53	.96
12	MOPAC-NS	3	11	0	IX	.91	.96
13	MOPAC-NS	3	1	1	IX	.87	.96

Notes:

1 Probability that the line segment survives.

2 Sections with no structures:

7, 8 ICG-ML



2. Highways

Table ____ contains highway survival probabilities for Carbondale. Maps of key highway sections are shown in Figures ____ and ____.

Four of the 16 sections in the study area have probabilities of survival below the criterion level of 90%. All of these routes occur in the outskirts of the city, so that accessibility within the city should not be seriously impaired.

The area of greatest concern is accessibility into the city from the north where both routes contain weak links, and from the west, where the remaining two weak links are located. All of these links have probabilities above 60%, with the weakest being on a redundant route from the north.

It is unlikely that Carbondale would suffer serious loss of accessibility due to a quake.

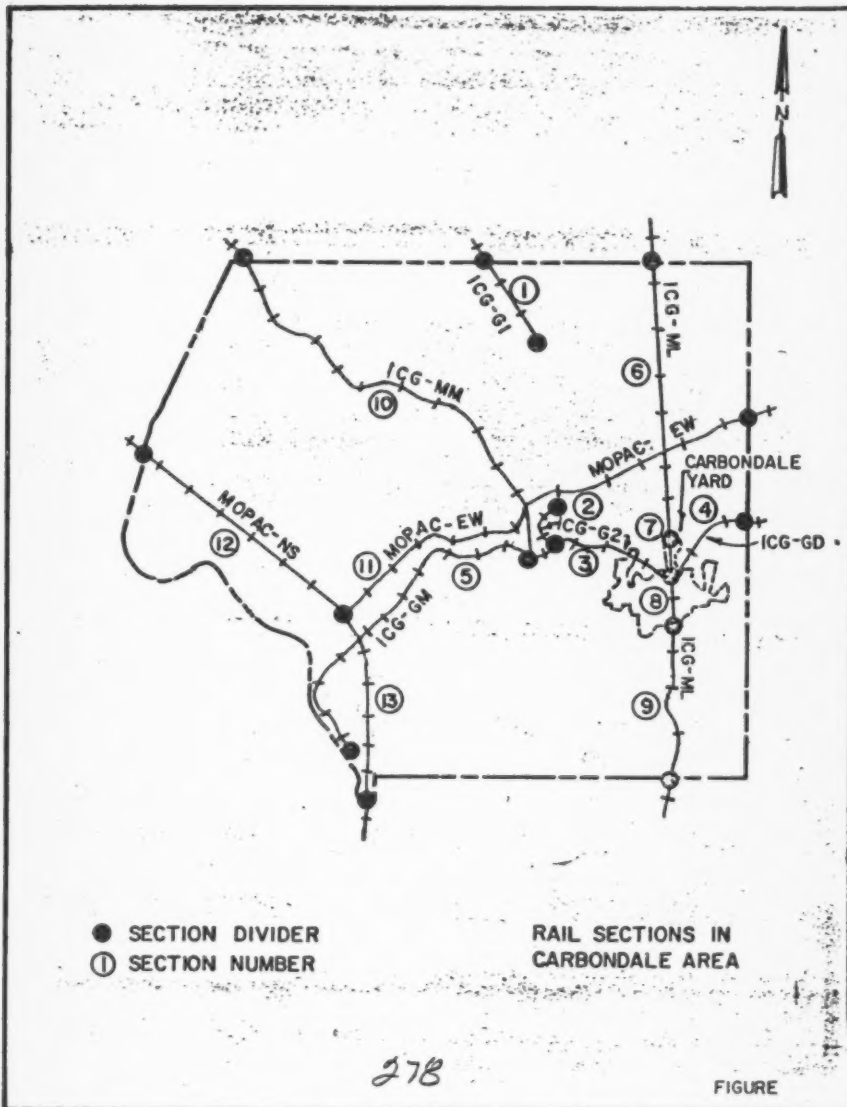


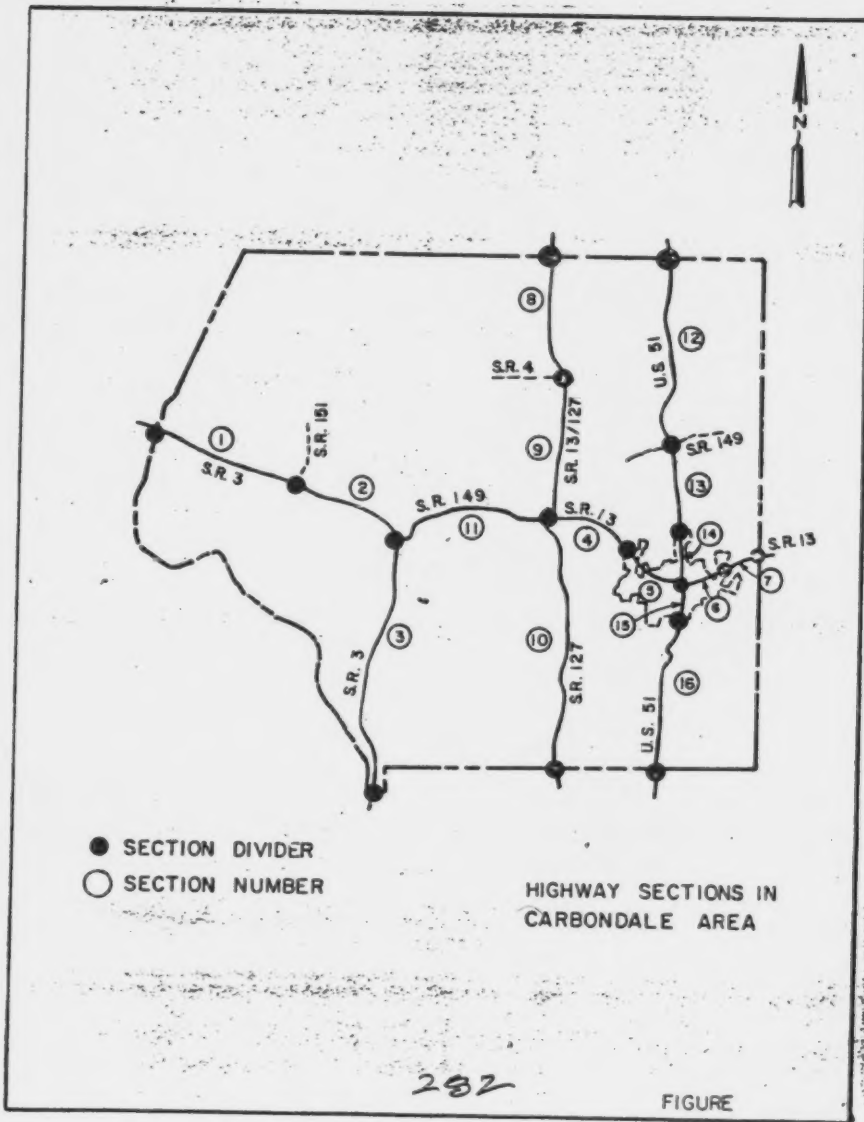
TABLE III-3-7

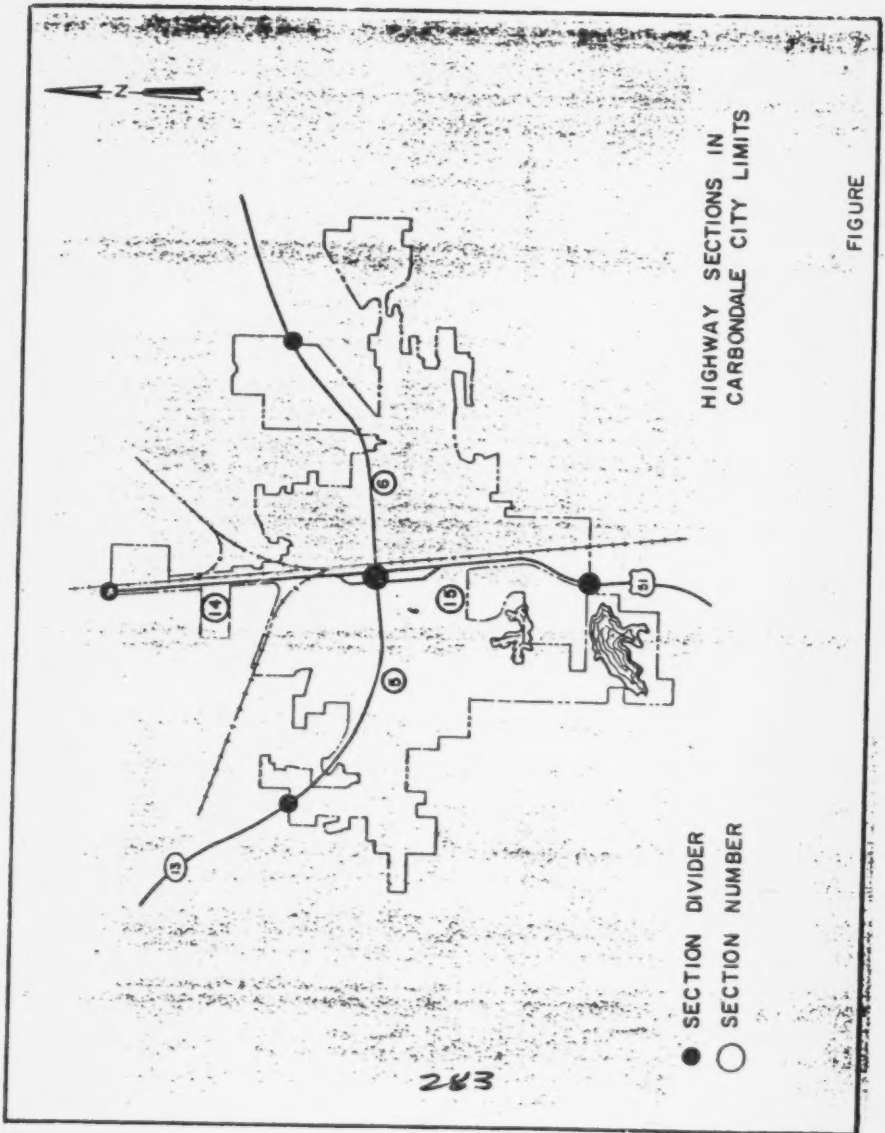
PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
CARBONDALE WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Route	Number of Structures Supporting Route		Number of Structures Over Route	Earthquake Intensity	P (Survival)	
		Single Structures	Pairs of Parallel Structures			Total Independent	Total Dependent
1	SR3	5	0	0	IX	.77	.94
2	SR3	1	0	0	IX	.94	.94
3	SR3	4	0	0	IX	.78	.94
4	SR13	0	4	0	IX	1.00	1.00
5	SR13	0	1	0	IX	1.00	1.00
6	SR13	0	2	0	IX	1.00	1.00
7	SR13	0	1	0	IX	1.00	1.00
8	SR13	2	0	0	IX	.92	.94
9	SR13	3	0	0	IX	.64	.74
10	SR127	2	0	2	IX	.90	.94
11	SR149	2	0	1	IX	.90	.94
12	US51	3	0	1	IX	.83	.94
13	US51	2	0	0	IX	.90	.94
15	US51	1	0	0	IX	.94	.94

Note:

- 1 Probability that the route segment survives.
2 Sections with no structures:
14, 16 US51





3. Docks (River Ports)

Carbondale does not possess dock or river port facilities.

4. Airports

As discussed in the general section on airports, (Section III.B.3.c.4.) airport runways will ^{generally} be at least partially available for use in Carbondale following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for others in the area of similar structural type. Figure _____ shows the location of major airport facilities for Carbondale.

FIGURE _____

Location of River Ports
and
Airports

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d. Public Utilities

1. Electric Utilities

General

Carbondale, population 23,000 is served by Central Illinois Public Service (CIPS). Three major transmission interconnects serves Carbondale's three bulk power substations which feeds five distribution substations. CIPS has 2,600 employees, five generating stations, two mobile spares, other spare substation transformers located throughout system and approximately 600 radio equipped vehicles.

CIPS's Grand Tower generating plant is located near Carbondale. Grand Tower has a total plant capacity of 195 MW. Figure _____ shows major elements of the Carbondale system.

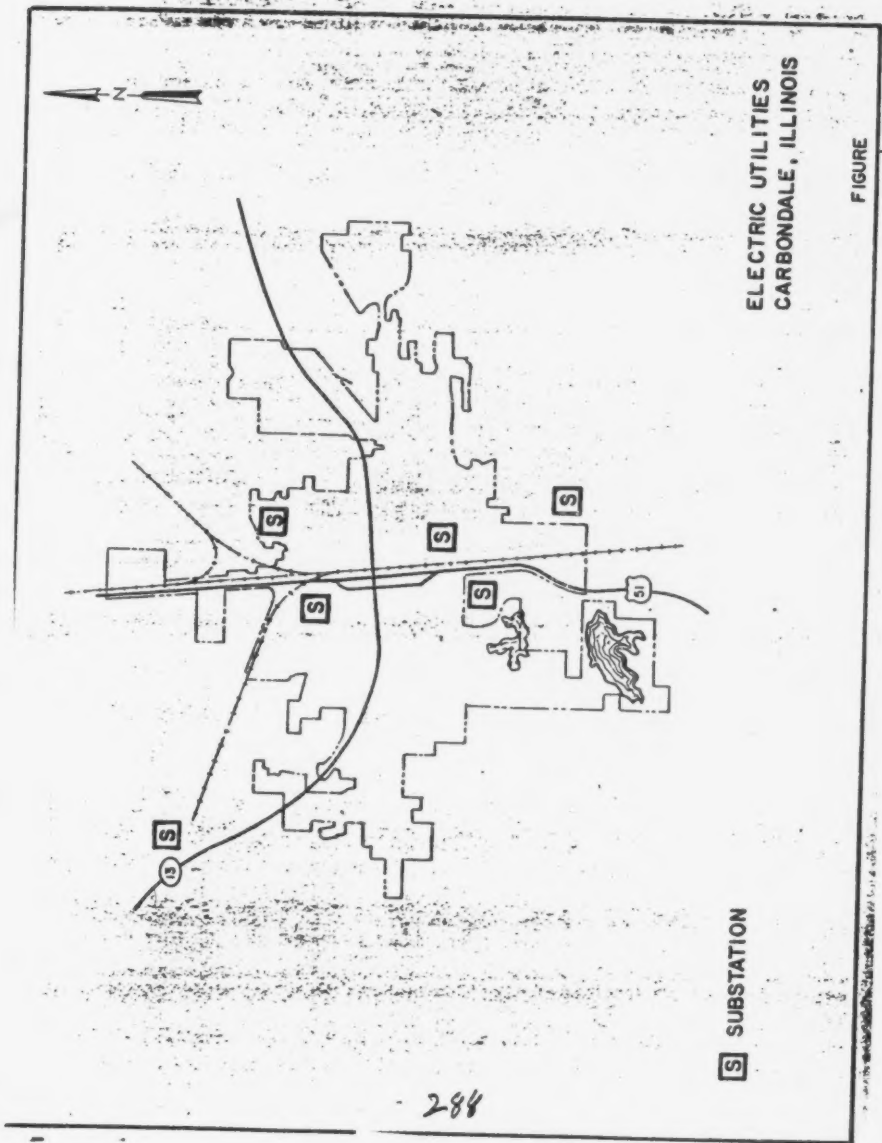
Availability Analysis

Table _____ presents the results of the availability analysis for this utility. Disruption to the system will be significant; the system is not expected to be available following the project earthquake.

TABLE _____
Availability of Electric Utilities

Carbondale

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 6	2/33%	—
Power Plants <u>1</u>	<u>0/0%</u>	—
TOTAL 7	2/29%	<u>No</u>



2. Water Utility

General

The Carbondale Water and Sewer Services Department serves the Carbondale Township, the South Highway Water District and the Crab Orchard Water District. The Department also has an agreement with the Kinkaid Water Conservancy District to supply water to Desoto and Elkhville during an emergency. The raw water source is Cedar Lake which is approximately four or five miles from the water treatment plant. Water is pumped directly to the water treatment plant or is stored in the Carbondale Reservoir located in the southern portion of the town.

The water plant capacity is 8.0 MGD. The treatment operations include coagulation, flocculation, filtration, and chlorination. There are three clearwells at the water treatment plant which have a total capacity of 3.45 MG. In addition, there are three storage locations in outlying parts of town. The Helen Street tank is elevated and has a 250,000 gallon capacity. A 750,000 gallon elevated storage tank is located on Chautauqua Street and the Bicentennial Industrial Park has a 500,000 gallon ground storage tank. Total storage capacity is 4.95 MG. The water distribution system consists of 4-inch through 14-inch ductile iron pipe. The system has one booster pumping station which is located at the Bicentennial Industrial Park for use in fire protection. The locations of the water treatment plant, storage facilities and booster pumping station are indicated in Figure ____.

Availability Analysis

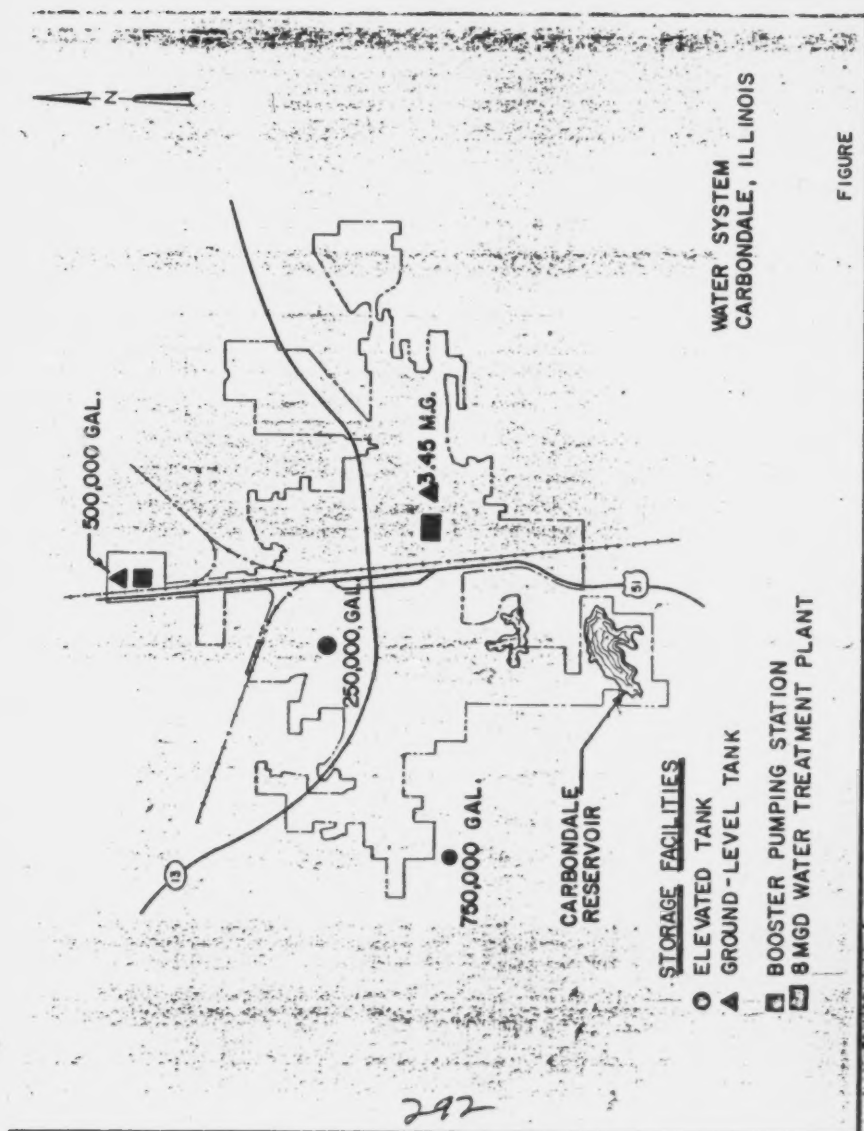
Table _____ presents the results of the availability analysis for Carbondale's water system. The fragility analysis indicates that serious damage to system elements is likely. This, combined with the expected loss of electricity, indicates that this system will not be available following the project earthquake.

Availability Analysis

Water Utility

Carbondale

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>System Availability (Yes/No)</u>
Treatment Plants: 1	0/0%	—
Storage Tanks elevated: 2	1/50%	—
Non-elevated 4	3/75%	—
Pump Station <u>1</u>	<u>0/0%</u>	—
TOTAL 8	4/50%	—
		NO



3. Natural Gas Utility

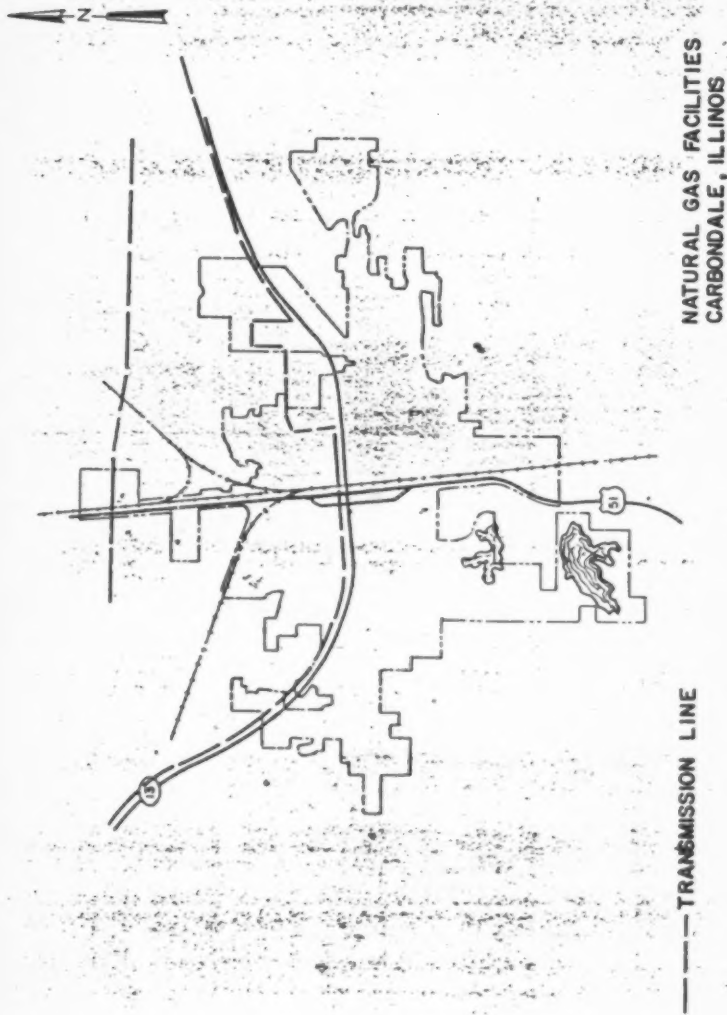
The natural gas system of Carbondale, Illinois is owned by Central Illinois Public Service Company. The system has one purchase point and buys its gas from Texas Eastern Transmission Company. There are no propane-air or LNG plants in the system. One hundred three (103) miles of piping make up the system, of which ninety-three (93) miles are steel and the remaining ten (10) miles plastic.

The steel and plastic piping making up the natural gas system serving Carbondale would fair well in a major quake. A few isolated piping ruptures might occur. However, damage to service piping and meter sets would require that the system be shut-off immediately following a major quake.

Some areas of the system could probably be restored to service within 24 hours to provide heat to a few selected areas near the system's single purchase point. The full system could be restored in one to two weeks. Major elements of this system are shown in Figure

Availability Analysis

As discussed above, this system is expected to be unavailable following the project earthquake.



FIGURE

4. Sewage System

General

The Carbondale Public Works Department operates two wastewater treatment facilities which serve the Carbondale Township. The Northwest wastewater treatment plant has a design capacity of 2.64 MGD. The activated sludge treatment operations include influent pumping, grit removal, clarification, aeration, and sludge digestion. The Northwest WWTP also has a near-by pretreatment facility on-site through which industrial wastewater is routed prior to treatment in the activated sludge plant. Treated wastewater is discharged into the Big Muddy River. The Northwest plant receives electrical power from two separate sources. No other auxiliary power source is available. The Southeast wastewater treatment plant is an activated sludge facility with a capacity of 3.9 MGD. The unit processes include an influent pumping station, a grit chamber, clarifiers, aeration basins, chlorine contact basin and sludge treatment facilities. The Southeast WWTP discharges the treated wastewater into Little Crab Orchard Creek. The plant is served by one electrical feed line. A gasoline operated generator provides auxiliary power to a portion of the plant. The location of the wastewater treatment plants are shown in Figure .

There are five wastewater pumping stations dispersed throughout the city. The sanitary and storm sewer systems are separate in Carbondale. The sanitary sewers are primarily clay pipe, ranging in diameter from 6 inches to 48 inches.

Availability Analysis

As shown in Figure _____, this sewage system is not expected to be available following the project earthquake. This is due to the materials of the pipe in the collection system, the probable loss of electric power and structural damage to treatment facilities.

Availability Analysis

Sewage Systems

Carbondale

Number of Structures Surveyed	
----------------------------------	--

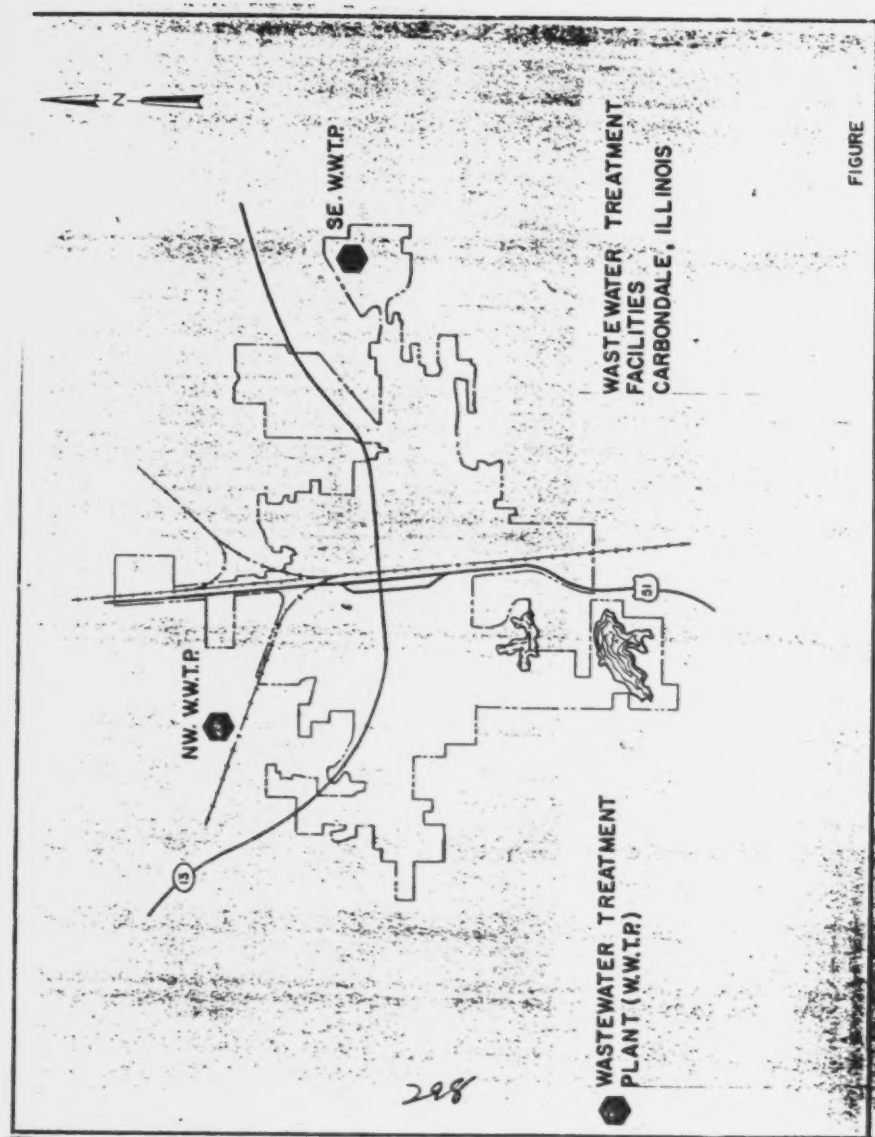
Treatment Plants	3
------------------	---

Structures Expected To be Available	
--	--

0/100%

System Availability (Yes/No)	
---------------------------------	--

No



FIGURE

5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.B.4. "Conflagrations"), following the general discussion of public utilities.

III.I. Poplar Bluff; General

The City of Poplar Bluff is located in the Bootheel region of southeastern Missouri. It is the least populous of six project cities, with a 1980 population of approximately 17,000. Poplar Bluff plays a significant role in the economy of this region, contributing in the areas of commerce, agriculture and medical services, four major hospitals being located in the city.

Physiographic Description (from Hopper, et al, 1983; CUSEPP Report #82-3):

Poplar Bluff is situated on the border between the Ozark Plateaus and the Mississippi Alluvial Plain (Fenneman, 1938). Most of the city is located on the mildly dissected uplands of the Ozark Plateaus west of the Black River; a small part of the city occupies the flat Mississippi Alluvial Plain east of Black River.

Figure _____ shows the hypothetical ground shaking intensities expected in Poplar Bluff, should the CUSEPP planning earthquake occur. These strong levels of ground motion would result in serious damage and disruption to Poplar Bluff, as reflected in the findings presented in this section.

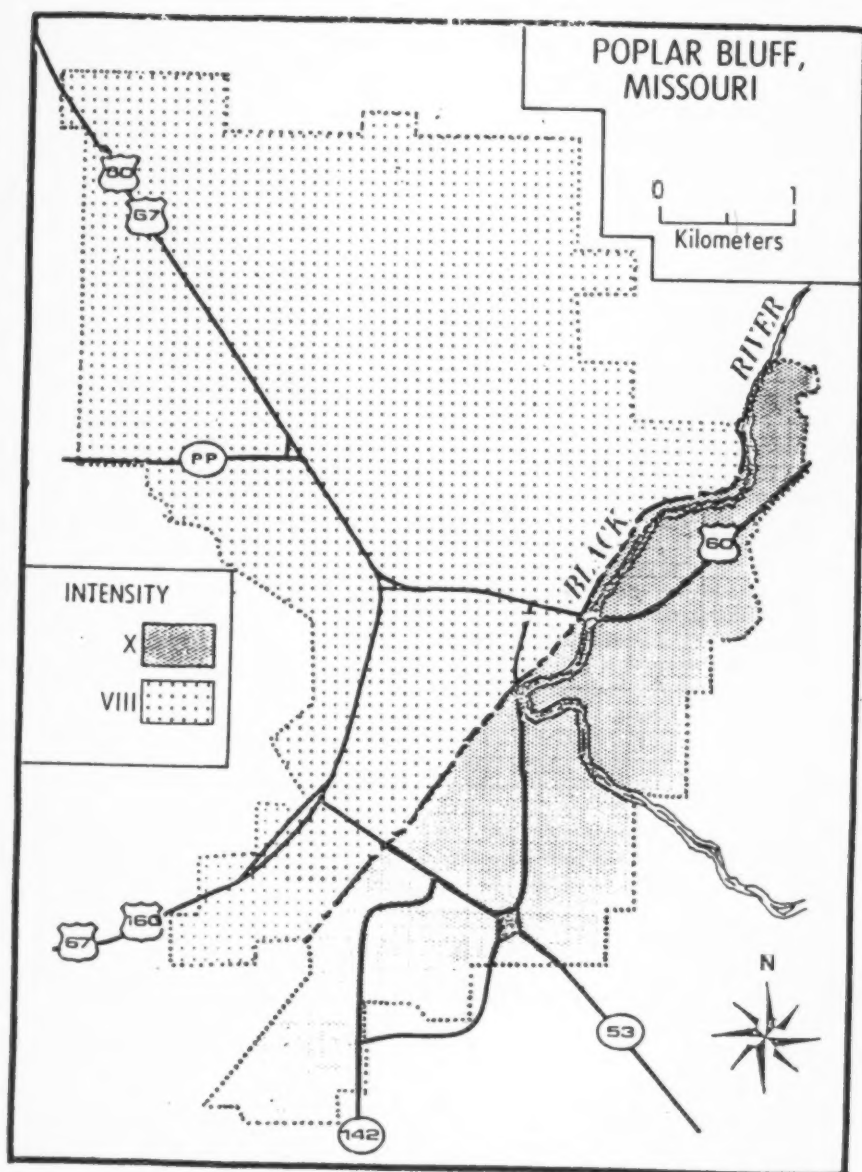


Figure _____ Hypothetical intensity map for Poplar Bluff, Missouri. For an earthquake near the north end of the New Madrid seismic zone, intensities projected for Poplar Bluff are: X on the Mississippi flood plain southeast of the city, but only VIII on the uplands to the northwest. For an earthquake near the south end of the New Madrid seismic zone, the intensities at Poplar Bluff would be lower.

from: Hopper, et al, 1983 (CUSEPD Report #82-3)

III.H.2. Effects on Medical Resources

Poplar Bluff possesses a full spectrum of medical services and facilities. These entities provide medical support to the city, surrounding communities and general region. Medical services surveyed during this project were: Major Hospitals, Health Manpower, Blood Banks, Clinical Laboratories and Ambulance Services.

Major Hospitals

This city is served by four major hospitals and serves as a required health center for southeastern Missouri. The major hospitals included seven major structures, which were surveyed during the project. Due to the strong ground shaking anticipated for Poplar Bluff, with an occurrence of the project earthquake, serious damage and disruption to these medical facilities is anticipated. Four of the seven surveyed structures (57%) are expected to be available following the project quake. Fortunately, these are associated with a better availability of hospital beds, 689 or 90%. All hospitals have emergency power units, which are expected to be available. Table _____ depicts the findings of the availability analysis.

Health Manpower

The discussion of this topic and presentation of findings for casualties expected to be suffered among health manpower in Poplar Bluff, is found in the general part of this section; i.e., Section III, part B.1.b.

TABLE _____
Availability of Major Hospital Facilities

<u>Major Hospitals Surveyed</u>	<u>Hospital Structures Surveyed</u>	<u>Beds in Surveyed Structures</u>	<u>Hospital Structures Expected to be Available/Percent</u>	<u>Beds Expected to be Available/Percent</u>	<u>Emergency Power Unit Available</u>
4	7	765	4 / 57%	689 / 90%	Yes

III.H.2.c. Blood Banks

Poplar Bluff

Availability of blood storage facilities in following the planning earthquake is shown in Figure _____. These structures are normally provided with emergency power units, which are expected to be available for service.

TABLE
BLOOD STORAGE FACILITIES
(Blood Banks)

Poplar Bluff

<u>Number of Facilities Surveyed</u>		<u>Number Expected to be Available</u>
Major Hospital:	4	2/50%
Non-Hospital:	<u>1</u>	<u>0/0</u>
Total	5	2/40%

III.H.2.d. Clinical Laboratories

The availability of clinical laboratory facilities in Poplar Bluff following an occurrence of the CUSEPP planning earthquake, is depicted in Figure _____. Those facilities associated with major hospitals can utilize the hospitals emergency power system. The availability of emergency power to non-hospital laboratories is not known.

TABLE _____
Availability of Clinical Laboratories
Poplar Bluff

	<u>Total Number</u> <u>Surveyed</u>	<u>Number Expected</u> <u>To Be Available/Percent</u>
Major Hospitals	4	2/50%
Other	<u>0</u>	<u>0</u>
Totals	4	2/50%

III.H.2.e. Ambulance Services

The availability of ambulance service structures in Poplar Bluff following an occurrence of the CUSEPP planning earthquake is depicted in Figure _____. As ambulances are frequently parked outdoors, the survival of the vehicles will be good, but difficult to quantify. Structures contain supplies, communications equipment and personnel, and thus contribute significantly to the providing of this service.

TABLE _____
Availability of Ambulance
Service Structures
Poplar Bluff

<u>Number of Structures</u>	<u>Number Expected to</u>
<u>Surveyed</u>	<u>Be Available/Percent</u>
1	1/100%

III.H.3. Casualties: Demands on Medical Resources

A. Casualties From Structural Failure

These findings, for the City of Poplar Bluff, are presented in the general part of this section, i.e., Section III, Part B.2.a. Casual figures and conclusions are discussed collectively in that section.

B. Displaced Persons and Available Shelter

Poplar Bluff is not expected to be affected by flooding following an occurrence of the CUSEPP planning earthquake. No casualties or displaced persons are anticipated due to flooding. Persons displaced by damage to residences, and school structures likely to be available for shelter, are also given in Table ____ below. Available school structures are listed again in the following sections enumerating available critical facilities.

TABLE
Displaced Persons and Available Shelter
Memphis

<u>Flooding</u>	<u>Damage to Residences</u>		<u>Total</u>	<u>School Structures</u>
	<u>Single</u>	<u>Multi-Family</u>		<u>Available</u>
-0-	2,443	3,300	5,743	1

TABLE
Availability of Police Services Structures
Poplar Bluff

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
-0-	N/A

3. Schools

Table ____ shows the expected availability of school buildings, for use as shelter and feeding large numbers of persons.

III.H.4. Effects On Critical Facilities

General

This part of the report will present availability of selected vital services, facilities and systems in Poplar Bluff, following the occurrence of the CUSEPP planning earthquake. These entities include public services and structures, communications, transportation and utility systems.

a. Public Services and Structures

1. Fire Services

Table ____ shows the expected availability of fire fighting structures. Since fire fighting vehicles and other equipment are typically located inside a structure, the loss of a structure contributes to the non-availability of needed equipment.

TABLE ____

Availability of Fire Service Structures
Poplar Bluff

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
1	1/100%

2. Police Services

Table ____ shows the expected availability of police service structures in Poplar Bluff.

TABLE
For Shelter Purposes.
Poplar Bluff

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>
30	1/3%

b. Communications

Table____ shows the expected availability of radio, television, and telephone structures in Poplar Bluff following the occurrence of a CUSEPP planning earthquake.

TABLE
Availability of Communications Structures
Poplar Bluff

<u>Total Structures</u>	<u>Structures Expected</u>
<u>Surveyed</u>	<u>To Be Available/Percent</u>

Radio
Television
Telephone

Data not collected

Total

C. Transportation Systems

1. Railroads

Survival probabilities for key rail bridges in Poplar Bluff are shown in Table _____. Figures ____ and ____ show the location of key rail sections.

Some loss of accessibility to Poplar Bluff by rail is likely as a result of the earthquake. Of the eight links only two have survival probabilities greater than 90%. Damage to this rail network would be second only to rail damage in Memphis.

The weakest link is MOPAC-B1 (sections 1 and 2) from the east. The combined survival probability of 8% (0.13×0.61) indicates it is very likely the route would be impassible.

From the south, MOPAC-ML (section 7), with a survival probability of 42%, is a weak link. The route most likely to survive is MOPAC-ML from the north.

TABLE III-3-6

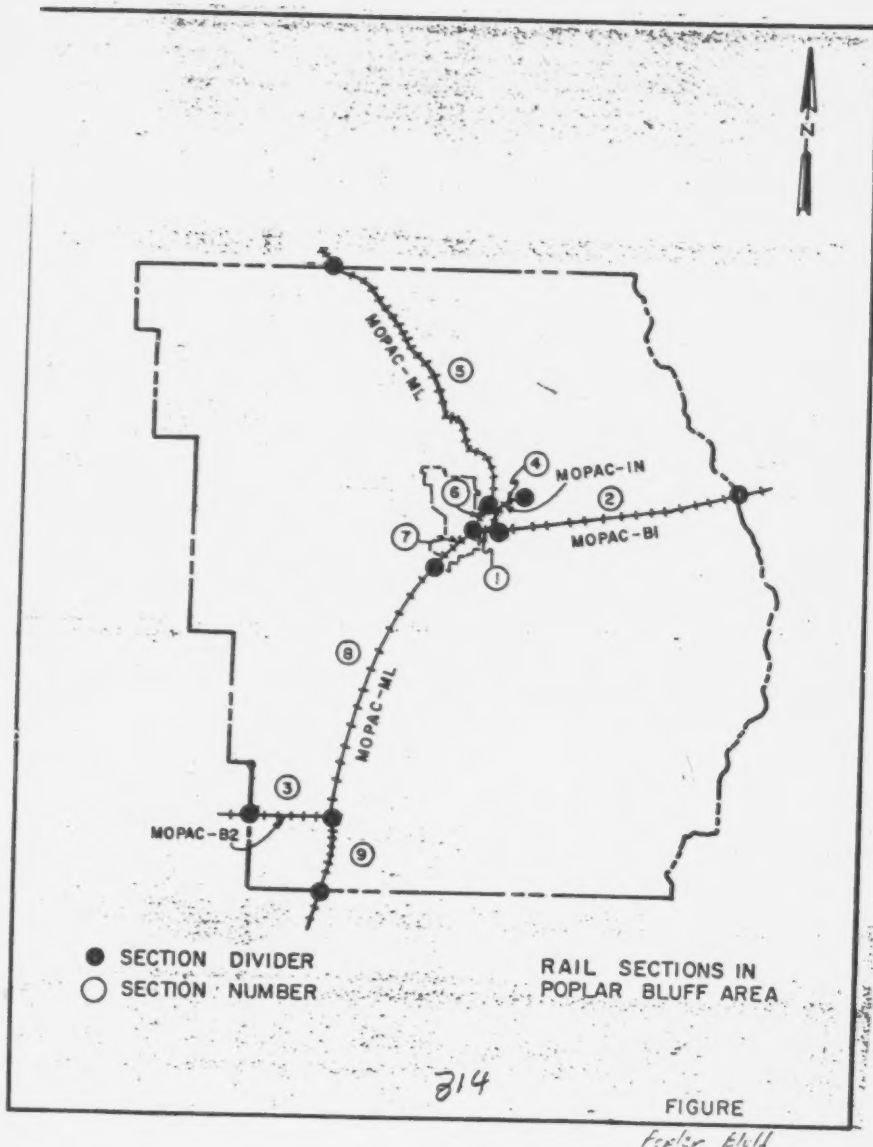
PROBABILITY THAT BRIDGES ON RAILROAD LINE SEGMENTS IN POPLAR BLUFF
WOULD SURVIVE NEW MADRID EARTHQUAKE

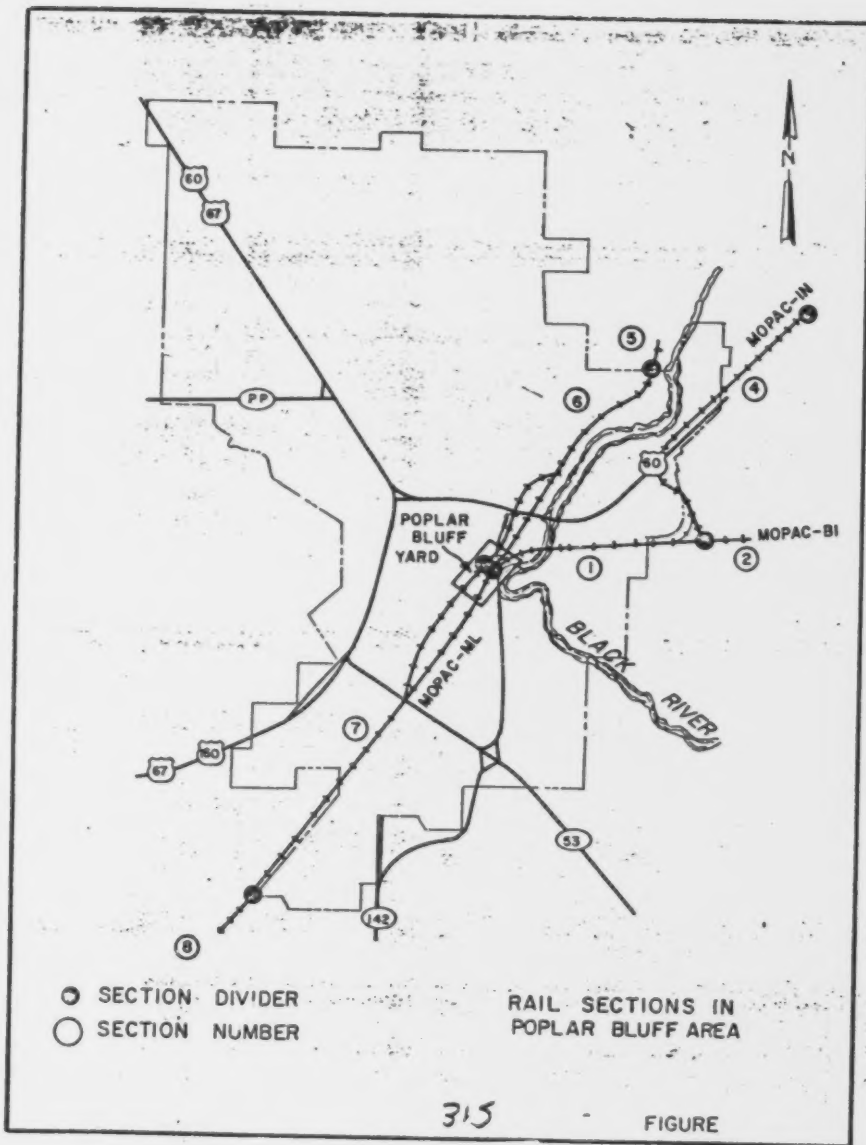
Section ²	Railroad & Line	Number of Structures Supporting RR Line		Number of Structures Over RR Line	Earthquake Intensity	P (Survival) ¹	
		Single Structures	Pairs Of Parallel Structures			Total Independent	Total Dependent
1	MOPAC-B1	2	0	0	X	.61	.78
2	MOPAC-B1	10	1	0	X	.13	.78
3	MOPAC-B2	5	0	0	VIII	.95	.99
4	MOPAC-IN	1	0	0	X	.78	.78
5	MOPAC-ML	5	0	1	VIII/X	.75	.78
6	MOPAC-ML	0	0	1	X	.98	.98
7	MOPAC-ML	1	1	2	X	.42	.78
8	MOPAC-ML	0	7	0	X	.71	.95

Notes:

1 Probability that the line segment would survive

2 Section with no structures:
9 MOPAC-ML





2. Highways

Survival probabilities for key highways in Poplar Bluff are found in Table _____. The highway system is depicted in Figures ____ and ____.

Highway availability in Poplar Bluff would almost certainly be reduced after an occurrence of the project earthquake. Of the 25 highways sections analyzed, 14 are candidates for failure, having survival probabilities less than 90%. Of that 14, eight have survival probabilities of less than 50%, and five less than 20%. These very low probabilities the potential extent of disruption to the transportation system.

Access from the east is very likely to be lost. Parts of the city east and south of the Black River may be reached by using roadways through the city, but this should be an area of concern. Access from the north-west on US 60 is likely to be available as is access from the south on US 67.

TABLE III-3-12

PROBABILITY THAT BRIDGES ON HIGHWAY ROUTE SEGMENTS IN
POPLAR BLUFF WOULD SURVIVE NEW MADRID EARTHQUAKE

Section ²	Route	Number of Structures Supporting Route		Number of Structures Earthquake Over Route Intensity	P (Survival)	
		Single Structures	Pairs of Parallel Structures		Independent	Total Dependent
1	SR53	1	0	0	.43	.43
2	SR53	1	0	0	.70	.70
3	SR53	5	0	0	.02	.43
4	SR53	2	0	0	.49	.70
5	SR142	2	0	0	.49	.70
6	SR142	6	0	0	.12	.70
8	SRPP	2	0	0	.98	.99
9	SRWW	1	0	0	.70	.70
10	US60	1	0	0	.99	.99
11	US60	4	0	0	.97	.99
14	US60	1	0	0	.99	.99
16	US60	1	1	0	.65	.70
17	US60	5	0	1	.15	.70
18	US60	5	0	0	.05	.43
19	US60	5	0	1	.16	.70
20	US60	5	0	0	.75	.78
21	US67	3	0	0	.76	.78
23	US67	2	0	0	.99	.99
24	US67	2	0	0	.88	.94
25	US67	5	0	0	.94	.97

Notes:

1 Probability that the route segment would survive

2 Sections with no structures:

7 SRPP
12, 13, 15 US60
22, 26 US67

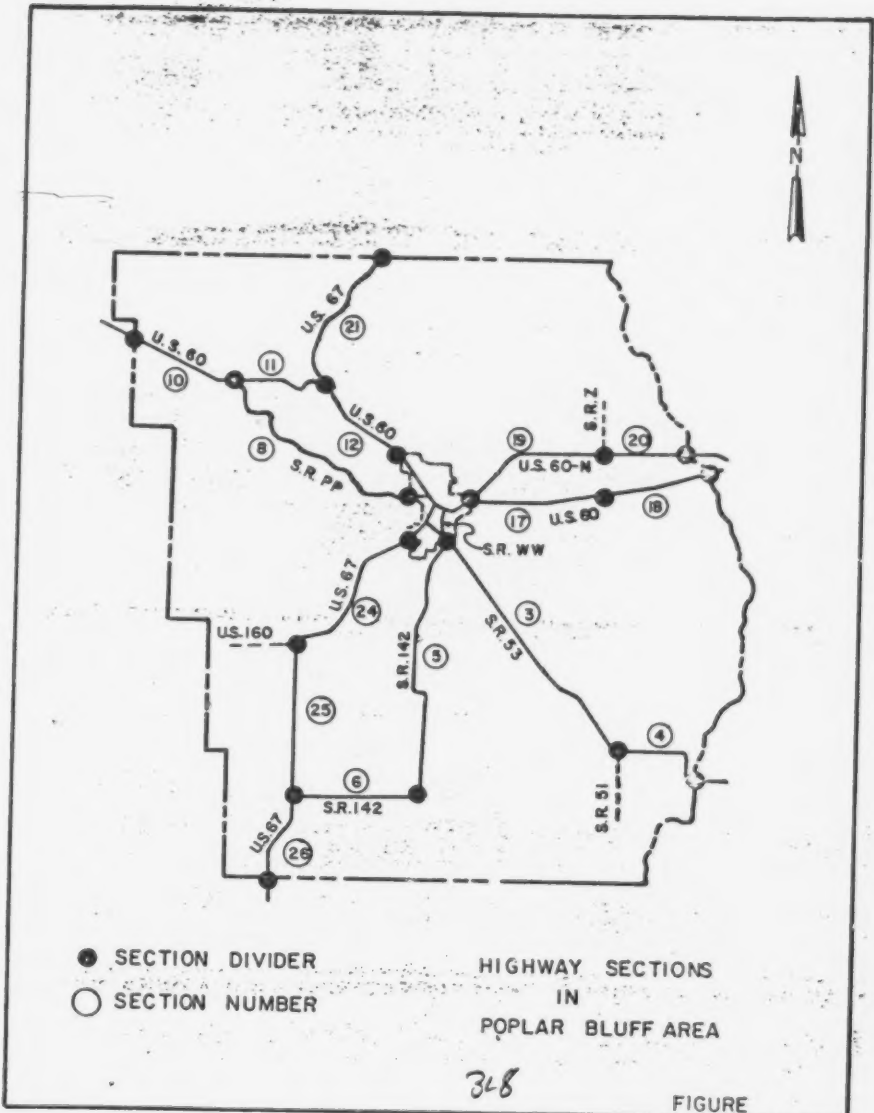
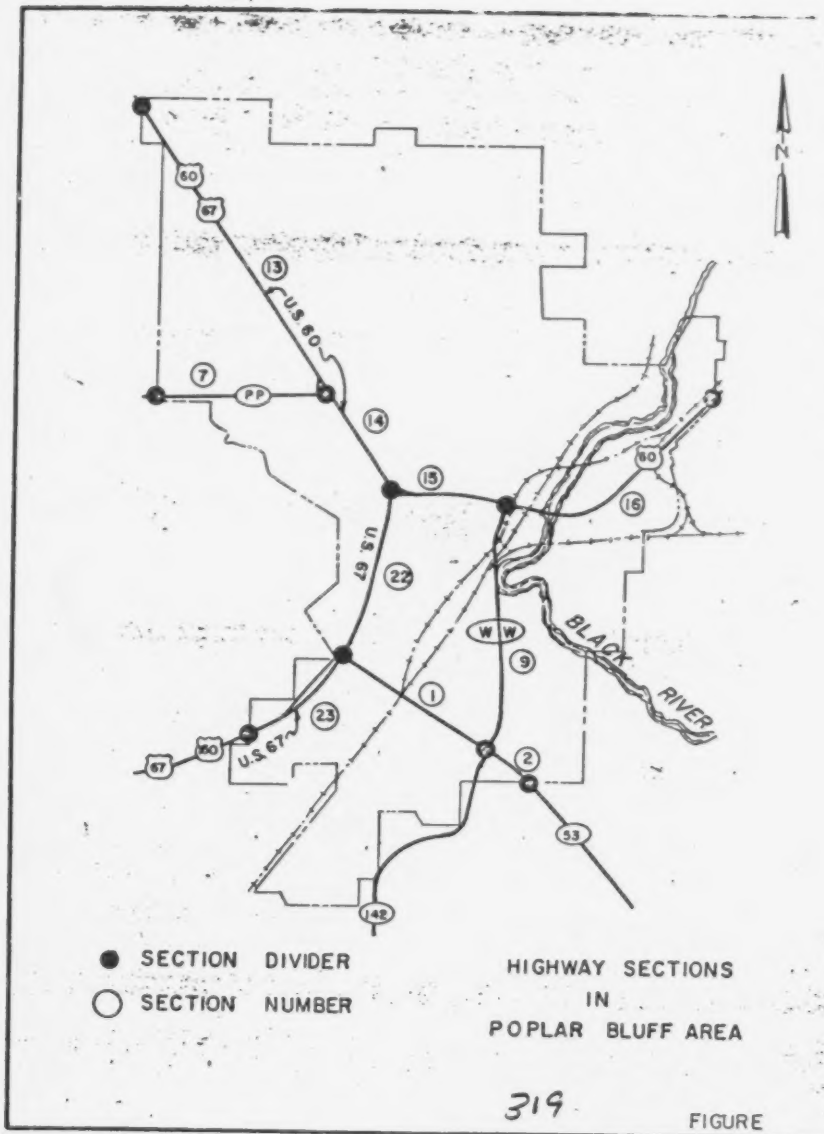


FIGURE
Poplar Bluff



3. Docks (River Ports)

Poplar Bluff does not possess dock or river port facilities.

4. Airports

As discussed in the general section on airports, (Section III.B.3.c.4.) airport runways will ^{generally} be at least partially available for use in Poplar Bluff following the project quake. Delicate and complex landing-aid instruments and devices, as well as general lighting, is not expected to be available. Airport buildings will sustain damage typical for others in the area of similar structural type. Figure _____ shows the location of major airport facilities for Poplar Bluff.

FIGURE _____
Location of River Ports
and
Airports

- this material to be supplied for Final Draft -

d. Public Utilities

1. Electric Utilities

General

Poplar Bluff, population 17,000 is served by Poplar Bluff Light and Water - Sewer Department (PBL&WSD) which purchases its power from SWPA and City of Springfield. One dual feed delivery point with two 161/69 kV transformers serves Poplar Bluff. Poplar Bluff could generate approximately one-third of its peak demand of 40,000 KW. This municipal system has 80 full time employees and a total of 39 radio equipped vehicles. PBL&WSD doesn't have access to a mobile spare, however, they have one 69/13 kV spare and future plans including purchasing a 161/69 kV spare transformer. Figure _____ depicts major elements of Poplar Bluff's electrical system.

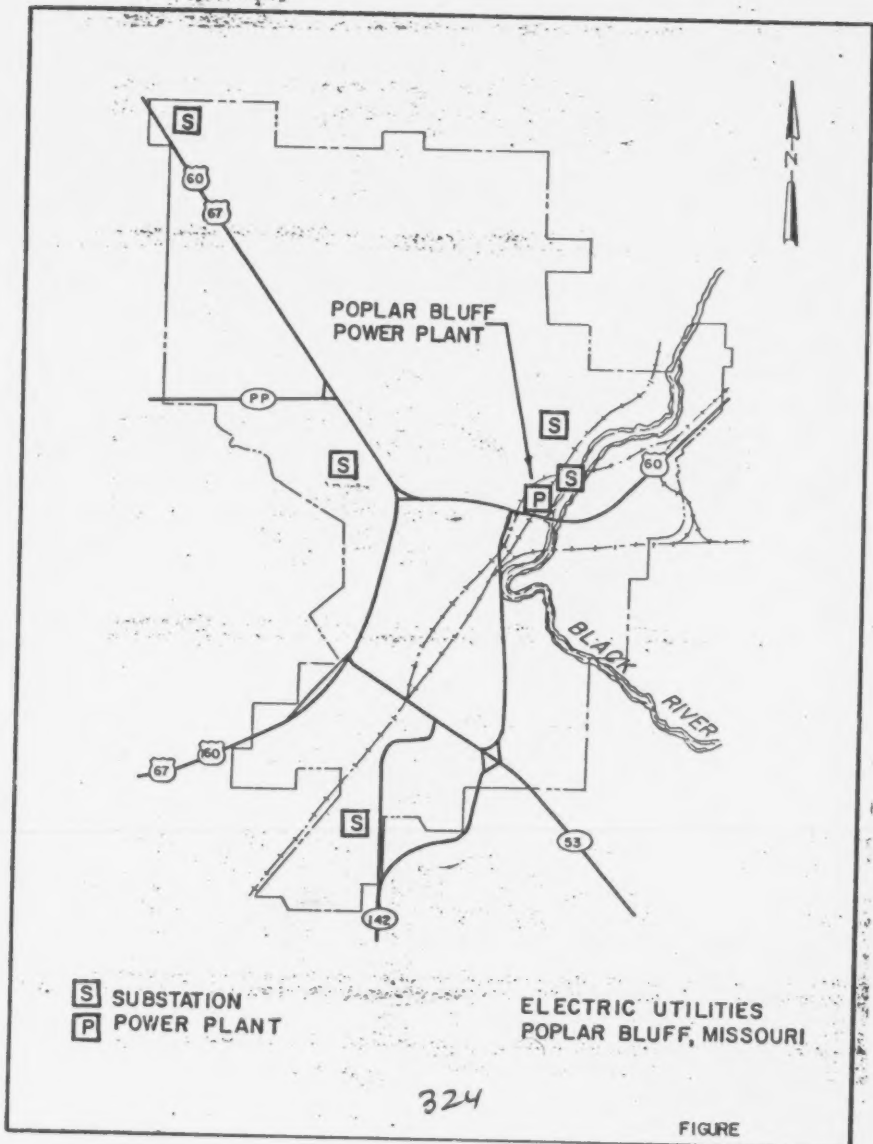
Availability Analysis

Table _____ presents the findings of the availability analysis for Poplar Bluff's electric utility. These results reflect the serious damage which is expected for this system. The system is not expected to be available following the project earthquake.

TABLE _____
Availability of Electric Utilities

Poplar Bluff

<u>Total Number of Structures Surveyed</u>	<u>Structures Expected To be Available/Percent</u>	<u>Overall System Availability (Yes/No)</u>
Substations 4	1/25%	—
Power Plant <u>1</u>	<u>0/0%</u>	—
TOTAL 5	1/20%	— No



2. Water Utility

General

The City of Poplar Bluff operates a 5.5 million gallon per day (MGD) water treatment plant. The average daily pumpage is approximately 3.5 to 4 MGD. There are two diesel powered emergency generators at the water treatment plant which are not presently connected to the system. The source of water for Poplar Bluff is the Black River. The water distribution system was initially installed in 1900. In the last ten or fifteen years, ductile iron or concrete water mains have been laid. Prior to that time the water pipes were gray cast iron lined with concrete. The distribution system consists primarily of 2 to 12 - inch pipe with some 14 and 16-inch pipe. An emergency booster pumping station is located in the northern portion of the City on Main Street.

The water storage facilities are located primarily in the northern portion of the city. However, the Poplar Bluff Industrial Park in the southern part of the city owns a 3 MG standpipe and pumping station which are connected to the Poplar Bluff system. There are two elevated water storage tanks in the city, having capacities of 500,000 gallons and 100,000 gallons. Additionally, there is a 1.5 million gallon standpipe with high service pumps. The total ~~storage~~ capacity in Poplar Bluff is 2.1 MG. The locations of the water treatment plant, storage facilities and booster pumping station are shown in Figure ____.

Availability Analysis

Figure _____ shows the findings of the availability analysis for Poplar Bluff's water system. The age of the distribution system, loss of electric power and expected damage to system elements contribute to the conclusion that this system is not expected to be available following an occurrence of the project earthquake.

Availability Analysis

Water Utility

Poplar Bluff

System Availability
(Yes/No)

Structures Expected
To be Available/Percent

Total Number of
Structures Surveyed

Treatment Plants: 1

Storage Tanks
elevated: 2

Non-elevated 2

TOTAL 5

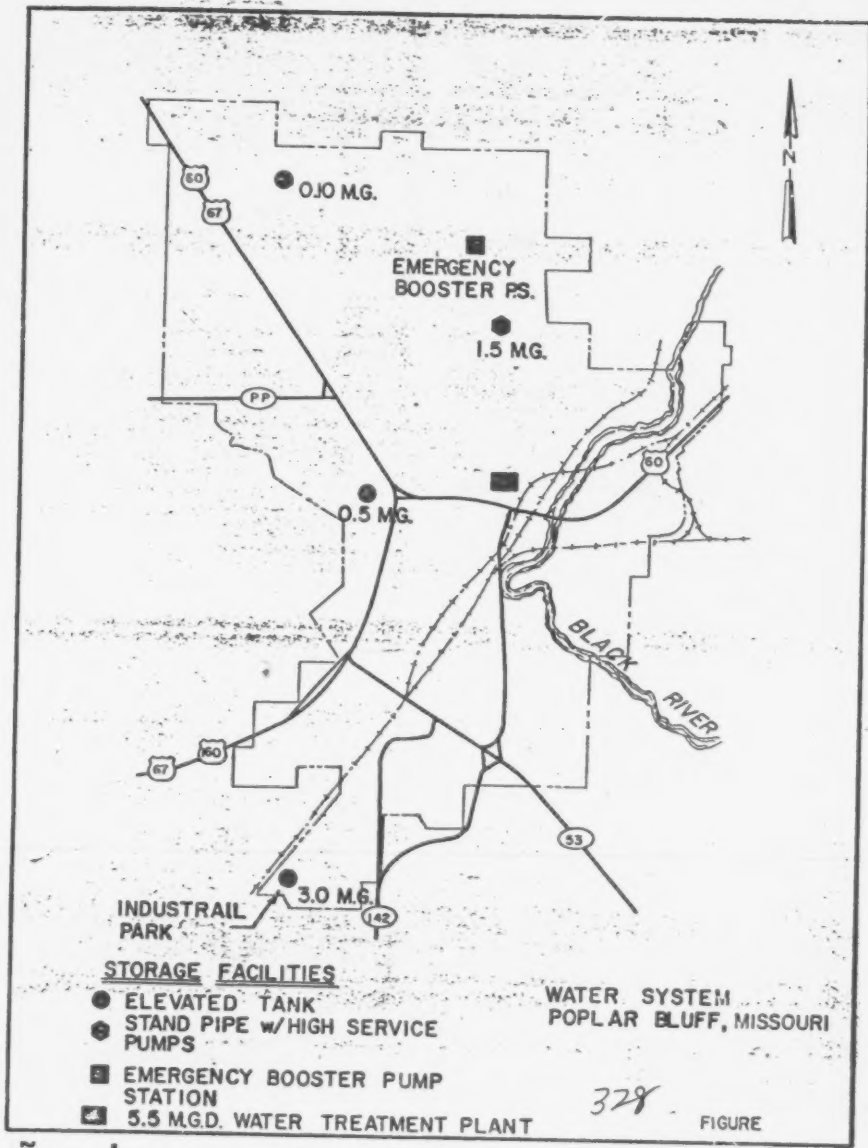
0/0%

1/50%

2/100%

3/60%

NO



3. Natural Gas Utility

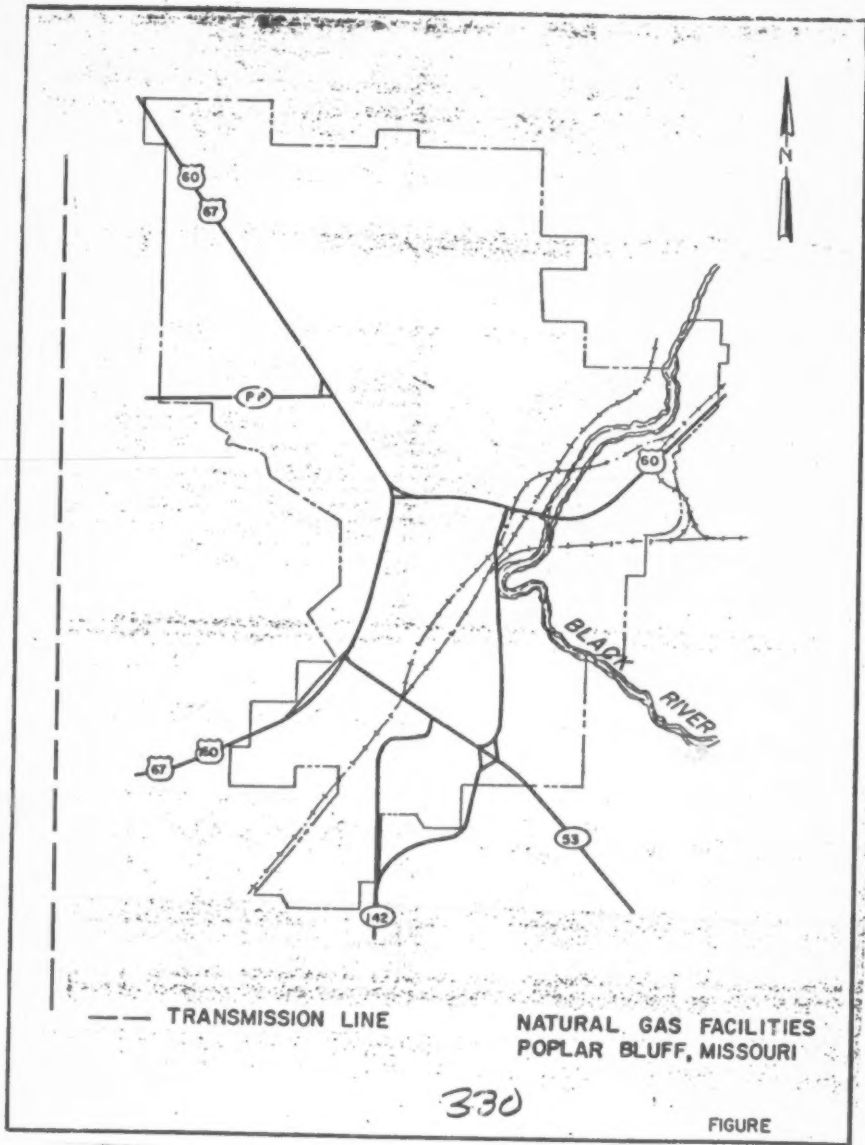
The natural gas system of Poplar Bluff, Missouri is operated by Laclede Gas Company. The system has one (1) purchase point and buys it's gas from Mississippi River Transmission Company. There is no propane-air or LNG plants in the system. Approximately 118 miles of piping make up the system, of which 99% is steel.

The steel piping in the system serving Poplar Bluff would suffer only scattered damage in the event of a major quake. Isolated ruptures occuring in the steel piping. However, damage to service piping and meter sets would require that the system be shut-off immediately following a major quake.

Some areas of the system could be restored to service within 24 hours to provide heat for a few selected areas. The full system could be restored in one to two weeks. Major system elements are shown in Figure ____.

Availability Analysis

As discussed above, this system is expected to be unavailable following the project earthquake.



4. Sewage Systems

General

The wastewater treatment system in Poplar Bluff consists of three 80 acre lagoons having a total capacity of 2.6 MGD. Each lagoon is a two stage facility with primary and secondary cells. The southeast lagoon discharges directly in the Black River. The south and southwest lagoons discharge into Drainage Ditch #7. The location of each lagoon is indicated in Figure _____. The city is served by eighteen (18) wastewater pumping stations. There are no auxiliary power facilities for the system. The storm and sanitary wastewater collection systems are separate. The sanitary sewers are primarily clay and range from 8 inches to 27 inches in diameter.

Availability Analysis

This system is not expected to be available following the project earthquake. Although treatment facilities consist of lagoons, which can be more resistant to damage than other kinds of treatment structure, the same elements are present here to disrupt service. Damage to collection system piping and loss of electric power are expected to significantly impair the system.

Availability Analysis

Sewage Systems

Poplar Bluff

Number of Structures
Surveyed

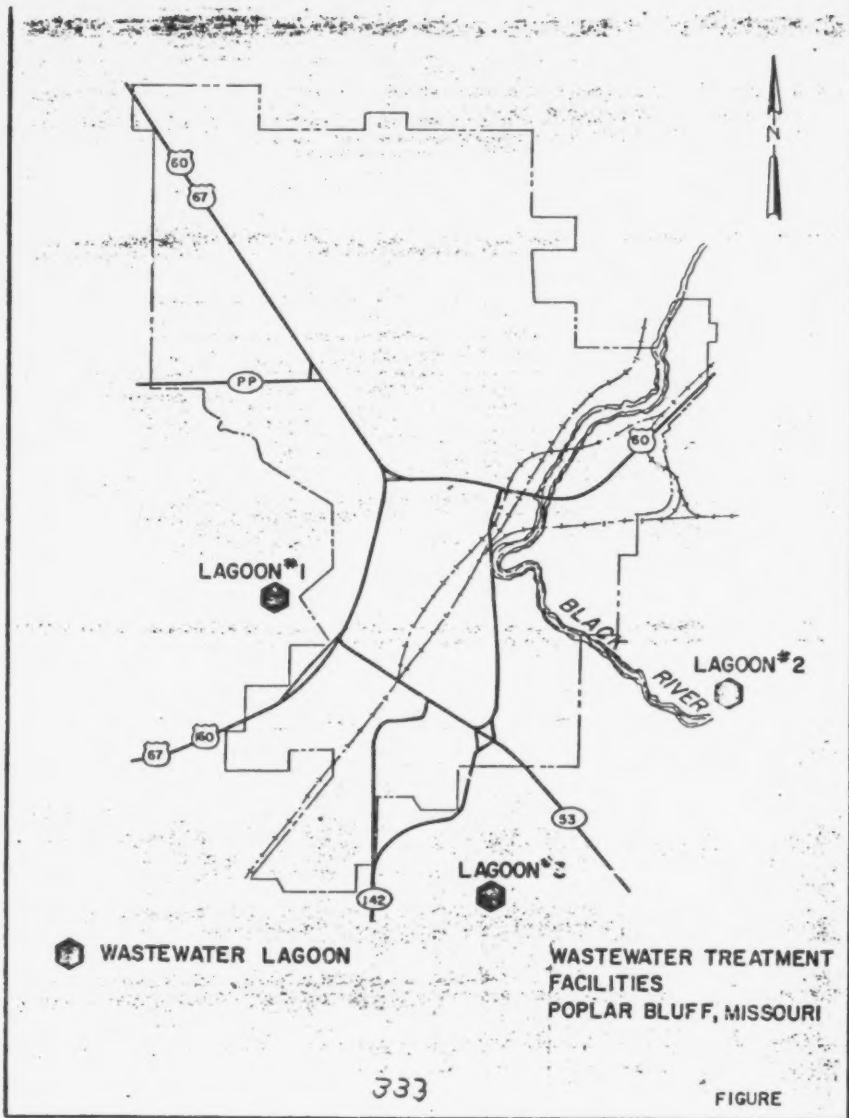
0

Structures Expected
To be Available

N/A

System Availability
(Yes/No)

No



5. Conflagrations

The findings of the project's analysis for this topic is presented in Section III, the general results sections (III.B.4. "Conflagrations"), following the general discussion of public utilities.

IV. ESTIMATE OF RESTORATION/REPLACEMENT COSTS

Methodology

A. Replacement/restoration costs were estimated for categories of structures. Analysis information which existed as a result of the damage and casualty assessment efforts was used to produce these estimates. The structural categories for which cost estimates were made are:

- single family residences
- multi-family residences
- "non-residential" structures, to include:
 - commercial, industrial
 - public noneducational
 - institutional
 - other
- schools
- hospitals
- critical facilities not covered elsewhere.

Average unit replacement/restoration and representative costs were developed which were typical and representative for the six project cities and the study area. Such costs were developed for each damage state and each structural category. These costs were based on current (i.e. late 1983) dollars.

Utility Services and Transportation Systems

Planning-type estimates of replacement/restoration costs were made for electric, water, gas, sewer, railroad and major arterial street systems for the six project cities. As with the cost estimates for structures, these estimates were made using information generated for

the damage and casualty assessments. Estimates are in 1983 dollars. These estimates of replacement/restoration costs were made by system experts who used the project's estimates and applied construction costs for recent similar projects in the project cities and study area.

MEMPHIS
Restoration/Replacement Cost Estimates for Structures

<u>Structure Type</u>	<u>Estimated Replacement/ Restoration Costs (Millions of Dollars)</u>
Single Family Residential	\$ 2,610
Multi-Family Residential	1,840
Commercial, Industrial and Institutional	16,378
Schools	881
Critical Facilities and Public Buildings, <u>not</u> including Utilities	181
Hospital Structures	205
	Sub-Total \$22,095

Restoration/Replacement Cost Estimates
for Utilities, Major Roads and Railroads
(Millions of Dollars)

Electric Utility	\$1,350
Water Utility	332
Gas Utility	418
Sewer Utility	386
Major Road	294
Railroad	128
	Sub-Total: \$ 2,908

Total Estimated
 Restoration/Replacement Costs: \$ 25,003
(Millions of Dollars)

LITTLE ROCK
Restoration/Replacement Cost Estimates for Structures

<u>Structure Type</u>	<u>Estimated Replacement/ Restoration Costs (Millions of Dollars)</u>
Single Family Residential	\$ 129
Multi-Family Residential	199
Commercial, Industrial and Institutional	1,054
Schools	39
Critical Facilities and Public Buildings, <u>not</u> including Utilities	23
Hospital Structures	19
Sub-Total: \$1,463	

Restoration/Replacement Cost Estimates
for Utilities, Major Roads and Railroads
(Millions of Dollars)

Electric Utility	\$ 268
Water Utility	59
Gas Utility	86
Sewer Utility	38
Major Road	1
Railroad	2
Sub-Total: \$ 454	

Total Estimated
 Restoration/Replacement Costs: \$1,917
(Millions of Dollars)

EVANSVILLE
Restoration/Replacement Cost Estimates for Structures

<u>Structure Type</u>	<u>Estimated Replacement/ Restoration Costs (Millions of Dollars)</u>
Single Family Residential	\$ 308
Multi-Family Residential	158
Commercial, Industrial and Institutional	4,144
Schools	74
Critical Facilities and Public Buildings, <u>not</u> including Utilities	41
Hospital Structures	56
Sub-Total \$ 4,781	

Restoration/Replacement Cost Estimates
for Utilities, Major Roads and Railroads
(Millions of Dollars)

Electric Utility	\$ 158
Water Utility	40
Gas Utility	109
Sewer Utility	41
Major Road	11
Railroad	1.4
Sub-Total: \$ 360	

Total Estimated
 Restoration/Replacement Costs: \$ 5,141
(Millions of Dollars)

PADUCAH
Restoration/Replacement Cost Estimates for Structures

<u>Structure Type</u>	<u>Estimated Replacement/ Restoration Costs (Millions of Dollars)</u>
Single Family Residential	\$ 145
Multi-Family Residential	200
Commercial, Industrial and Institutional	2,563
Schools	41
Critical Facilities and Public Buildings, <u>not</u> including Utilities	26
Hospital Structures	27
	Sub-Total \$ 3,002

Restoration/Replacement Cost Estimates
for Utilities, Major Roads and Railroads
(Millions of Dollars)

Electric Utility	\$1,348
Water Utility	8
Gas Utility	5.4
Sewer Utility	15
Major Road	12.4
Railroad	6.2
	Sub-Total: \$ 1,395*

*includes cost of
1750 megawatt
Powerplant @ \$1,313

Total Estimated
Restoration/Replacement Costs: \$ 4,397*
(Millions of Dollars)

CARBONDALE
Restoration/Replacement Cost Estimates for Structures

<u>Structure Type</u>	<u>Estimated Replacement/ Restoration Costs (Millions of Dollars)</u>
Single Family Residential	\$ 69
Multi-Family Residential	89
Commercial, Industrial and Institutional	516
Schools	95
Critical Facilities and Public Buildings, not including Utilities	34
Hospital Structures	6
	Sub-Total: \$ 809

Restoration/Replacement Cost Estimates
for Utilities, Major Roads and Railroads
(Millions of Dollars)

Electric Utility	\$ 178
Water Utility	10
Gas Utility	13
Sewer Utility	11
Major Road	19
Railroad	26
	Sub-Total: \$ 257

Total Estimated
 Restoration/Replacement Costs: \$1,066
 (Millions of Dollars)

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